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(54) **Method and associated apparatus which achieve imaging device/media compatibility and color appearance matching**

Verfahren und dessen Vorrichtung um Bildaufnahmeverrichtung/Medienkompatibilität und Farberscheinungsübereinstimmung zu erhalten

Procédé et appareil pour arriver à une compatibilité dispositif/média d'imagerie et une concordance d'apparence de couleurs

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EP-A- 0 531 891 **DE-A- 4 305 693**
US-A- 5 057 913 **US-A- 5 208 903**

• **JOURNAL OF PHOTOGRAPHIC SCIENCE,**
vol.17, no.6, November 1969, LONDON GB
pages 198 - 204 HUNT ET AL 'The Tone
Reproduction of Colour Photographic Materials'

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Description

Cross-Reference To Related Applications

[0001] Reference is hereby made to U.S. Patent No. 4,958,220 entitled COLOR IMAGING APPARATUS PRODUCING VISUALLY MATCHED DISPLAYS OF PERCEPTUALLY DISTINCT REPRODUCED IMAGES, issued September 18, 1990, in the names of P. Alessi et al., on December 27, 1988; to U.S. Patent No. 4,979,032 entitled COLOR IMAGING APPARATUS PRODUCING ON VARIOUS IMAGE-RECEPTIVE MATERIALS A VISUALLY MATCHED HARD COPY REPRODUCTION OF A VIDEO IMAGE DISPLAYED, issued December 18, 1990, in the names of P. Alessi et al., to U.S. Patent Application Serial No. 931,889 Corresp. to EP No 9190251.1. (with publication number EP-A-0 460 187) entitled Methods And Associated Apparatus for forming Image Data Metrics which Achieve media Compatibility for Subsequent Imaging Applications a continuation of an application filed on December 22, 1989, in the names of E. Giorgianni and T. Madden;

Technical Field of The Invention

[0002] This invention relates generally to color image reproduction methods and associated apparatus. More particularly, the invention relates to reproduction methods and associated apparatus for producing image color encoding which achieves compatibility for disparate imaging media used together for input, output, manipulation and/or storage, when the intent of said methods and apparatus includes the retention of the color appearance of input images.

Background Of The Invention

[0003] Color image reproduction systems known in the art permit images to be captured by certain image-receptive media or devices, possibly digitized and stored, and then output onto complementary media. So, for instance, color images may be first captured on negative film and then reproduced on negative photographic paper. Such images may or may not pass through a digital intermediary. In another case, color images may be captured on positive photographic materials, known as transparencies, and then viewed directly by projection or back-illumination, or copied onto larger or smaller transparencies, or printed onto positive photographic paper. Again, such images may or may not pass through a digital intermediary. In yet another case, color images may be captured as an electronic signal by a video camera, and then viewed on a video monitor or converted to print by a device such as a thermal printer. Again, such images may or may not pass through a digital intermediary. The foregoing are just some samples of color image reproduction systems. The application of this invention is not limited to

the above examples, but may be applied to other color imaging systems as well, for instance to the reproduction of reflection originals using photographic, electrostatic, or other means.

[0004] Color-imaging systems in which the image passes through a digital intermediary allow improvements to be made to an image using a single means which may be a digital computer. Thus, improvements to an image's color and tone scale as well as to its sharpness and noise can be made in a convenient and adaptable way. Furthermore, if the imaging system includes a means for rapid viewing of the changes, the content of an image can also be edited in a convenient fashion. Many of these types of improvements are known to those skilled in the art. For example, U.S. Patent No. US-A- 4,500,919 entitled "COLOR REPRODUCTION SYSTEM" by W. F. Schreiber, discloses an image reproduction system of one type in which an electronic reader scans an original color image and converts it to an electronic image. A computer workstation and an interactive operator interface, including a video monitor, permit an operator to edit an image by means of displaying it on the monitor. When the operator has composed a desired image on the monitor, the workstation causes the output writer device to make an inked output of the reproduced image. Such systems are often referred to as "hybrid" imaging systems because they combine elements of photographic or other chemical-based imaging together with various elements of electronic imaging systems.

[0005] A hybrid color imaging system of significantly greater value would have the ability to produce appropriately rendered reproductions of input images from any of a plurality of original image-receptive media and/or devices using any of a plurality of output image-receptive media and/or devices regardless of the origin of the original input image. If this capability were incorporated in a hybrid imaging system, images originally captured on negative film, for instance, could be shown on a video monitor as well as be printed onto negative or positive photographic films or papers. Likewise, images originally captured on positive film could be shown on a video monitor as well as be printed onto negative or positive photographic films or papers. Additionally, images from various reflection media could be shown on a video monitor as well as be printed onto negative or positive photographic films or papers, or video or other forms of electronic images could be printed onto negative or positive photographic films or papers. Furthermore images from any of these input sources could be printed using a thermal, ink-jet, or electrostatic printing means as well as many other means known in the art. In all cases, it would be desirable for the final printed or displayed images to appear appropriately rendered for the reproduction medium selected to produce and/or display the final image and for the specific application of that final image.

[0006] An improved color-imaging system would

also provide the capability of storing image-bearing signals or digitized images for later display in such a manner that the display device, whether it produces hard copy using photographic paper, thermal dye transfer, electrostatic, or any other printing means, or a soft copy such as a video image, is not required to make any adjustments based on the original image capture medium or image source in order to make appropriately rendered reproductions of said images.

[0007] An improved color-imaging system would further provide the capability to produce output images, from various input media or sources, that are appropriately rendered using any of a number of output or display means. In each case, images would be rendered in a way that is appropriate based on the capabilities and limitations of the specific output device and/or medium and on the specific application for which the image is being produced.

[0008] An improved color-imaging system would additionally provide the capability to mix portions of images from various input media or sources and to then produce an appropriately rendered composite image using any of the various output and display means. For instance, one might wish to merge a portion of an image captured on one medium, such as positive transparency film, with a portion of an image captured on another medium, such as color negative film, and produce a single composite image on another medium, such as a video display, so that the entire composite image has an homogeneous and appropriate appearance.

[0009] A final consideration for an improved color-imaging system is that in order to optimally display or reproduce color images, it is often necessary to correct for variations in overall exposure and color balance due to exposure control errors of image capturing devices, variations in color temperature of the taking illuminants, and other factors. These balance adjustments are particularly important for an imaging system which has the previously described capability to merge portions of several images into a composite image. Different balance adjustments, and other types of image modifications, may be necessary for each input image in order to produce a completely homogeneous-appearing composite image. A practical color-imaging system should therefore provide a convenient means to apply these balance adjustments and other image modifications. An improved hybrid color-imaging system would further provide this capability without requiring references to the origin of the input image.

[0010] Those skilled in the art will recognize the particular difficulty of successfully exchanging, storing, adjusting, and producing homogeneous-appearing composite images of merged imaging data when disparate sources of input, many of which may not be designed specifically for use in hybrid imaging systems, are to be included as potential inputs to such imaging systems.

[0011] Images on photographic films and papers,

for example, are frequently used as input for hybrid imaging systems; yet these media are generally not designed specifically for purposes directly related to hybrid imaging. They are instead most often designed for direct viewing by a human observer or for printing onto other photographic materials. The different requirements for photographic negatives, photographic prints, photographic transparencies, graphic arts prints, and other forms of images result in a disparity and an inherent incompatibility among potential input image types. Image data typically derived from disparate input sources is incompatible in that it can not be directly exchanged, stored, adjusted, used to produce homogeneous-appearing composite images, or sent to an output device without requiring knowledge of the origin of each input image.

[0012] There are two fundamental causes of this incompatibility among image types. The first is that most positive imaging media are designed to be directly viewed by a human observer in a specific viewing environment. Reflection prints and most pieces of artwork, for example, are designed to be observed in a normal viewing environment, i.e., where the illumination of the image is similar in luminance level and chromaticity to the illumination of the rest of the viewing environment. Transparencies, on the other hand, are often designed to be projected in a darkened room or illuminated by back-light. These and other differences in the viewing environment will cause significant differences in a human observer's perception of an image. Imaging media designed for direct viewing by a human observer must, therefore, be designed for specific intended viewing environments. Each medium must be designed so as to properly compensate for perceptual effects that its associated viewing environment will induce in the human observer.

[0013] A measuring device, such as an input scanner in a hybrid imaging system, is of course not subject to the same perceptual effects as the human observer. As a consequence, measurements of images on disparate media will not directly correspond to the appearances of images on such media, even if those measurements correspond to CIE or other colorimetric standards and recommended practices. For example, if a typical 35mm photographic transparency is measured colorimetrically and that colorimetry is exactly reproduced on a reflection print, the reflection print will appear to be extremely dark, much too high in luminance contrast, and cyan-blue in overall color balance. This is because the transparency material has been specifically designed to be viewed in a darkened room where perceptual effects such as general brightness adaptation, lateral brightness adaptation, and partial chromatic adaptation will be induced in the human observer such that the transparency image will appear to be properly rendered in that particular viewing environment. Because the measured colorimetric values for the transparency designed for dark projection do not

correspond to the visual appearance of that transparency, colorimetric data scanned from that transparency is incompatible with data scanned from a reflection print or from any other form of image designed to be viewed in a normal viewing environment.

[0014] US-A- 5 037 913 discloses a CRT photographic printer having a video display monitor that simulates the appearance of a print to be made. The display portion of the printer includes a lighting condition correction unit that corrects the video signal sent to the display for lighting conditions where the monitor is installed. The lighting condition correction unit is programmed by printing a reference image for test purposes, displaying the reference image on the monitor, visually comparing the printed reference image with the monitor display to empirically determine a correction amount, and inputting the correction amount using standard printing correction keys. The correction is used to shift a table of printing reference data, and the shifted reference data is stored in the lighting condition correction unit.

[0015] The present invention addresses other perceptual issues, not addressed in that application, including the incompleteness of the observer's chromatic adaptation, lateral brightness adaptation (which can affect the observer's perception of luminance contrast), and general brightness adaptation (which affects the observer's perception of brightness) as they apply to input image incompatibility.

[0016] Moreover, the present invention addresses a second fundamental cause of incompatibility among input images that is also not addressed by the invention of the aforementioned application. This second fundamental incompatibility results because some input sources, such as photographic negatives and some forms of digital images, do not contain rendered output imaging information, i.e., information relating directly to an image intended to be viewed directly by an observer. These input sources produce rendered output images, intended for viewing, only when printed or otherwise output to an appropriate device and/or medium. Colorimetric data measured directly from such input sources is therefore fundamentally incompatible with colorimetric data measured directly from reflection prints, slides, and other forms of rendered images. Colorimetric data measured directly from a photographic negative, for example, would essentially correspond to the appearance of the negative itself rather than to a rendered positive image that would result if, for example, the negative were to be optically printed on to a photographic paper using and enlarger or other printing means.

[0017] As a result of these two fundamental causes of input image incompatibility, imaging data derived from photographic negatives, photographic transparencies, photographic and other forms of reflection images, and electronic sources of input cannot be used together to meet the interchange, storage, adjustment, and image-merging objectives described for this invention

unless such data are given special treatment.

[0018] U.S. Patent Application serial No. 931,889, corresponding to EP-A- 0 460 187 entitled Methods And Associated Apparatus for forming Image Data Metrics which Achieve media Compatibility for Subsequent Imaging Applications, filed in the names of E. Giorgianni and T. Madden, provides one method for meeting these stated objectives. In that application, a system is described in which compatibility of the input images is achieved by removing, as far as possible, all media-specific properties of each input medium. Compatibility is achieved by the transformation of each input to a common meaning or interpretation, i.e., the colorimetry of the original scene, or other source of exposure, which caused the input image to form on the input imaging device and/or medium.

[0019] While that solution is optimal for certain types of imaging systems, other types of systems may have different objectives which cannot be achieved by that approach. In graphic arts and desktop imaging, for example, the input image to be scanned, not the original scene, is generally considered to be the original image, and the imaging system must be capable of making a copy or other type of reproduction that is a visual match of the input image. In addition, these types of imaging systems may also require the capability for the straightforward generation of colors to user-provided colorimetric specifications.

[0020] It is the intent of the present invention, therefore, to provide novel methods and means which produce compatibility among inherently disparate forms of image inputs and which achieve that compatibility for image storage, adjustment, manipulation and merging in a way that additionally provides the capability to produce copies and other forms of appearance matches on any of a plurality of output devices and media and under any of a plurality of output viewing conditions. It is a further intent of this application to include the capability for producing colorimetrically specified colors on any output device and/or medium.

Summary Of The Invention

[0021] These intents are achieved by the method of claim 1 and the apparatus of claim 4.

[0022] In view of the foregoing, an object of the present invention is to provide an improved color imaging system.

[0023] A further object of the present invention is to provide methods and means for improved calibration of color imaging systems.

[0024] A further object of the present invention is to provide methods and means for novel calibration of color imaging systems which achieve media compatibility for subsequent imaging applications.

[0025] A further object of the present invention is to provide methods and means for encoding image data for color imaging systems such that images so encoded

can be output onto any of a plurality of image-receptive media or image-forming devices so that the reproduced images appear appropriately rendered for the output medium or device chosen regardless of the input image origin, images may be stored for later use without requiring documentation of their origin, images or portions thereof from various media and devices may be merged together to produce composite images of homogeneous and appropriate appearance, and images may be balanced and otherwise manipulated or adjusted without requiring references to their origin.

[0026] A further object of the present invention is to provide methods and means to achieve all of the above stated objects while additionally providing a color imaging system with the capability to produce copies, other forms of appearance matches, and other forms of appropriately rendered images from any input image.

[0027] A further object of the present invention is to provide a color imaging system with the capability of producing colorimetrically specified colors onto any output device or medium.

[0028] To achieve these objects, the present invention provides methods and means for transforming input image data to an intermediary color image processing and/or storage encoding which provides compatibility among disparate sources of input images while additionally providing the capability of matching the appearance of said input images or otherwise producing appropriately rendered images on any of a plurality of output devices and/or media for any of a plurality of viewing conditions.

[0029] To that end, image-bearing signals, such as those produced by scanning, with a reflection or transmission scanner, sources of rendered (i.e., in a form intended to be viewed directly) input images, are converted to a novel image manipulation and/or storage encoding, wherein said encoding is equal to the corresponding colorimetric values that would be required to match, in the viewing conditions of a uniquely defined reference viewing environment, the appearance of an input image as that image would appear if viewed in a specified input viewing environment. The viewing conditions of the reference viewing environment may correspond to an actual viewing environment, or they may instead correspond to an idealized viewing environment. The viewing conditions of the specified input environment may correspond to an actual input viewing environment, or they may instead correspond to those of a viewing environment generally intended for the type of input imaging device or medium.

[0030] Also to that end, the image-bearing signals from unrendered (i.e., not in a form intended to be viewed directly) input images, such as those scanned from a photographic negative or those provided by an electronic source, are first computationally rendered for a specified complementary image-producing device and/or medium and viewing environment to produce a computationally rendered image. The input image is

encoded in terms of the colorimetric values that would be required to match, in the viewing conditions of the reference viewing environment, the appearance of the computationally rendered input image as it would appear if viewed in the specified input viewing environment.

[0031] When these two techniques are used together in a color-imaging system, image data from all rendered input images, including images from media that are intended to be viewed under different viewing conditions, are made compatible with each other. In addition, image data derived from rendered input images is made compatible with image data derived from unrendered input images. Furthermore, all image data so encoded are compatible with color data entered directly by colorimetric specification.

[0032] It will be understood by those skilled in the art that while it is the intent of these methods to achieve compatibility among the inputs, it is not the intent to make images input from different sources indistinguishable from one another (as is the intent of Application Serial No. 931,889, corresponding to EP-A- 0 460 187). To do so would negate the premise of the present invention that compatibility shall be achieved while also providing the capability to produce output images which match the appearance of input images. By the use of the described methods of this invention, a necessary and sufficient degree of compatibility is achieved such that images input from any medium or device may be matched in appearance or otherwise appropriately rendered on any output device/medium without requiring documentation of the origins of the input images. Images may also be manipulated, adjusted, or stored for later use without requiring documentation of their input origins, and images or portions thereof may be merged together to produce composite images of homogeneous appearance.

[0033] The above and other objects of the present invention will become more apparent when taken in conjunction with the following description and drawings wherein like characters indicate like parts and which drawings form a part of the present invention.

Brief Description of The Drawings

[0034]

Fig. 1 is a block diagram of one embodiment of the invention.

Fig. 2 is a detailed block diagram illustrating the technique for forming the transform 58 of Fig 1.

Figs. 3 is a block diagram of another embodiment of the invention.

Fig. 4 is a detailed block diagram illustrating the technique for forming the transform 59 of Fig. 3.

Figs. 5 is a block diagram of yet another embodiment of the invention.

Fig. 6 is a detailed block diagram illustrating the technique for forming the transform 60 of Fig. 5.

Figs. 7 is a block diagram of another embodiment of the invention.

Fig. 8 is a detailed block diagram illustrating the technique for forming the transform 61 of Fig. 7.

Figs. 9 is a detailed block diagram illustrating the technique for forming the transform 72 of Fig. 7.

Fig. 10 is a detailed block diagram illustrating the technique for forming the transform 74 of Fig. 7.

Figs. 11 is a map illustrating the connecting relationship of Figs. 11a, 11b, and 11c.

Figs. 11a, 11b, and 11c are block diagrams of color reproduction apparatus in accordance with an embodiment of the invention.

Detailed Description Of The Preferred Embodiments

[0035] Fig. 1 shows, in block diagram form, a color image reproduction apparatus in accordance with a first preferred embodiment of the invention. One or more reflection image scanners 14 serve for scanning input images on one or more reflective media 12 and for producing image-bearing signals in digital form for each picture element of a reflection image being scanned. A computer-based workstation 26, which receives the image-bearing signals, transforms the input image-bearing signals into an intermediary image data encoding. The workstation also allows for archival storage of the intermediary image data using any of a variety of archival storage devices 28, and media such as magnetic tape or disk, or optical disk. The workstation also enables the operator to modify (color and/or composition) the original image to construct the image for reproduction. For that purpose, a video display 30 serves to display an image corresponding to video-transformed image-bearing signals provided by the workstation. Control apparatus 32, which may include a keyboard and cursor, enables the operator to provide image manipulation commands pertinent to modifying the video image displayed and the reproduced image to be made or stored. One or more output devices, 34, which may be film writers, thermal, ink-jet, electrostatic, or other type of printers, or electronic output devices then receive modified and output-transformed image-bearing signals from the workstation for output onto appropriate image-receptive media 36.

[0036] In this first embodiment, the objects of the

invention, which include achieving compatibility of images obtained from multiple reflection scanners and media, are achieved by converting the image-bearing signals produced by scanning a reflection print with a reflection scanner to an image manipulation and/or storage encoding, hereafter referred to as Database Color Encoding, corresponding to the colorimetric values that would be required to match, in the viewing conditions of a uniquely defined reference viewing environment, the appearance of an input image as that image would appear if viewed in a specified input viewing environment. That specified input environment may correspond to an actual viewing environment or to the viewing environment generally associated with the reflection input imaging medium. The reference viewing environment need not correspond to any actual environment. It may instead be defined to be conceptually or mathematically convenient, for example. The reference viewing environment must, however, be uniquely defined in terms of:

1) Surround - a description of the relationship of the luminance and chrominance of the light illuminating the image to the luminance and chrominance of the areas immediately surrounding the image.

2) Adaptive white point - a white reference, the luminance of which would appear to correspond to that produced by a 100% diffuse reflecting white object, and the chromaticities of which would appear achromatic (neutral) to an observer adapted to the viewing environment.

3) Viewing flare - the amount of non-image stray light in the environment that reaches the eyes of the observer, which may be expressed as a percentage of the luminance level associated with the reproduction of a 100% diffuse reflecting white object in the original scene.

[0037] The specified input viewing environment for each input image must also be defined in terms of surround, adaptive white point, and viewing flare. In addition, the spectral power distribution of the viewing illuminant must be specified in order to perform the required colorimetric measurements and/or computations.

[0038] The present invention provides a method and means for generating a data-set from which transformations are derived to convert image-bearing signals from input reflection prints, and other image-receptive media viewed in input viewing environments in which the surround corresponds to the surround associated with the reference viewing environment, to the Database Color Encoding values.

[0039] Referring to Fig. 2, patterns of specified arrays of R, G, B (red, green, and blue) exposure values or other image-forming values, chosen to produce colors which adequately sample and cover the useful

color range of the reflection medium 12 being calibrated, are created by pattern generator 40 and are fed to image-forming apparatus 42. The image-forming apparatus 42 produces one or more test images 46, consisting of approximately 400 test colors, on reflection medium 12. The test images may be created using a variety of methods appropriate for the application. These methods would include, but would not be limited to, using an exposing apparatus such as a sensitometer, using the output device of a color imaging apparatus, or directly recording images of test objects from original test objects or reproductions of test objects on intermediary imaging media. The reflection medium is then processed chemically or by other means appropriate for the specific medium to produce the test images. The colorimetric values for each test color of the test images are then determined by a measuring device 48. Colorimetric measuring device 48 may utilize, for example, spectrophotometric, spectroradiometric, or colorimetric measurements and colorimetric computational techniques, known to those skilled in the art, for the specified illuminant of the viewing environment for the reflection input medium. If the amount of viewing flare in the specified input viewing is different from that of the reference viewing environment, the computed colorimetric values must be transformed by a viewing-flare transform 50 to the corresponding colorimetric values for the amount of flare specified for the reference viewing environment. This transformation may be performed by adding or subtracting, as appropriate, the difference between the amounts of flare light or by using other techniques known to those skilled in the art. For example, if the colorimetric measurements and computations for the color patches are for 0.0% viewing flare, the input viewing environment is specified to be 1.0% viewing flare, and the reference viewing environment is specified to be 0.0% viewing flare, then flare-adjusted colorimetric values can be determined by computing the results of additively mixing 1.0% of the viewing illuminant with the measured colorimetric values.

[0040] If the adaptive white point of the specified input viewing environment is different in chromaticity from that of the reference viewing environment, the transformed colorimetric values must be further transformed by a chromatic adaptation transform 52 to the corresponding colorimetric values for the adaptive white point of the reference viewing environment. This transformation may be performed by using a chromatic adaptation transform, such as a VonKries transformation matrix, or by using other techniques known to those skilled in the art. For example, if the flare-adjusted tristimulus values of the input viewing environment are defined as $X_f Y_f Z_f$, and the corresponding tristimulus values for the reference viewing environment are defined as $X_c Y_c Z_c$ (chromatic-adaptation-corrected), then the transformation is written as:

$$\begin{pmatrix} X_c \\ Y_c \\ Z_c \end{pmatrix} = M * \begin{pmatrix} X_f \\ Y_f \\ Z_f \end{pmatrix}$$

where matrix M is the VonKries transformation matrix consistent with the chromaticities of the adaptive white points of the input and reference viewing environments.

[0041] In some cases, the chromaticities of the adaptive white point will correspond to the chromaticities of the viewing illuminant. In other cases, however, observer chromatic adaptation may be incomplete. As a result, the chromaticities that would appear achromatic to the observer may be different than those of the viewing illuminant. The degree of chromatic adaptation will depend on the absolute luminance level of the viewing environment, the particular chromaticity values of the illuminant, and other factors. The determination of the adaptive white point is best done by psychophysical experiments in which the observer, adapted to the viewing environment, identifies a stimulus which appears to be achromatic and which appears to correspond in luminance to a 100% diffuse reflecting object.

[0042] The values from chromatic-adaptation transform 52 may be further transformed by a color metric conversion 54, for example to convert from CIE XYZ units to CIE 1976 $L^*a^*b^*$ units, to form Database Color Encoding values. The Database Color Encoding values represent the corresponding colorimetric values that would be required to match, in the viewing conditions of the reference viewing environment, the appearance of an input image, on the reflection medium calibrated, as that image would appear if viewed in the specified input viewing environment.

[0043] Test images 46 are additionally read by reflection scanner 14 which produces image-bearing signals corresponding to each test color. A transform apparatus 56 then creates a transform 58 that relates the image-bearing signal values for the input medium colors to the determined Database Color Encoding values of the corresponding test colors.

[0044] Referring again to Figure 1, transform 58 is subsequently used in workstation 26 to transform input images, scanned from reflection medium 12 using reflection scanner 14, to Database Color Encoding values. Transforms similar to transform 58, appropriate for images on reflection medium 12 but for different input viewing conditions, may be derived according to the methods of this embodiment. Transforms appropriate for images on other reflection media and other types of media designed to be viewed in the surround condition of the reference viewing environment may also be derived according to the methods of this embodiment. Input images so transformed are made compatible with each other, consistent with the image-storage, image-

adjustment, image-manipulation, and image-merging objects of this invention.

[0045] Fig. 3 shows, in block diagram form, a color image reproduction apparatus in accordance with a second preferred embodiment of the invention. Again, one or more reflection image scanners 14 serve for scanning input images on one or more reflective media 12 and for producing image-bearing signals in digital form for each picture element of the reflection image being scanned. In addition, one or more transmission image scanners 18, serve for scanning input images on one or more positive transparency media 16 and for producing image-bearing signals in digital form for each picture element of the positive transparency image being scanned. The computer-based workstation 26, which receives the image-bearing signals from both types of scanners, transforms the input image-bearing signals into an intermediary image data encoding. The remainder of the blocks function as described in Fig. 1.

[0046] In this second embodiment, the objects of the invention which include achieving compatibility of images obtained from multiple reflection scanners and media and images obtained from multiple transmission scanners and positive transparency media are achieved by converting the image-bearing signals from positive rendered images, for example, those produced by scanning an image from a transparency film with a transmission scanner, to a database encoding representative of the corresponding colorimetric values that would be required to match, in the viewing conditions of the reference viewing environment, the appearance of an input image as that image would appear if viewed in a specified input viewing environment.

[0047] The present invention provides a method and means for generating a data-set from which transformations are derived to convert image-bearing signals from input transparencies intended for projection in a darkened room, and from other image-receptive media viewed in viewing environments in which the surround differs from that associated with the reference viewing environment, to Database Color Encoding values.

[0048] Referring to Fig. 4, patterns of specified arrays of R, G, B exposure values or other image-forming values, chosen to produce colors which adequately sample and cover the useful color range of the to be calibrated positive transparency medium 16, are created by the pattern generator 40 and are fed to the image-forming apparatus 42. The image-forming apparatus produces one or more test images 46, consisting of approximately 400 test colors on the positive transparency medium 16. The test images may be created using a variety of methods appropriate for the application. These methods would include, but would not be limited to, using an exposing apparatus such as a sensitometer, using the output device of a color imaging apparatus, or directly recording images of test objects from original test objects or reproductions of test objects on intermediary imaging media. The positive transparency

medium is then processed chemically or by other means appropriate for the specific medium to produce the test images 46. The colorimetric values for each test color of the test images are then determined by the chromatic measuring device 48, for the specified illuminant of the viewing environment for the input medium. If the amount of viewing flare in the specified input viewing is different from that of the reference viewing environment, the computed colorimetric values must be transformed by the viewing-flare transform 50 to the corresponding colorimetric values for the amount of flare specified for the reference viewing environment. This transformation may be performed as previously described or by using other techniques known to those skilled in the art.

[0049] The transformed colorimetric values are then further transformed by a surround-transform 51 in order to account for the difference between the surround of the reference viewing environment and the surround specified for the input viewing environment.

[0050] In particular, the surround factor S described below of surround-transform 51 is used to account for a perceptual effect, known to those skilled in the art as lateral brightness inhibition, which may be induced by an image's surround and which may alter an observer's perception of image luminance contrast. The value of this surround factor, which is defined to have a value of 1.00 for a normal surround in which the illumination of the image is similar in luminance to the luminance of the surround, is affected by factors such as absolute luminance levels, image size, and other factors. The determination of the value of the surround factor is best done by psychophysical experiments in which the observer, successively adapted to each viewing environment, identifies images which appear to match in luminance contrast.

[0051] For example, if the input viewing environment is specified to have a dark surround, as for projected transparencies, and the surround of the reference viewing environment is specified as normal, then the first-transformed colorimetric values must be further transformed to account for the perceived lowering of the luminance contrast induced by the dark surround. This transform may be performed using any of a number of techniques known to those skilled in the art.

[0052] In addition, the luminance factors β_d and β_n described below of surround-transform 51 are used to account for a second perceptual effect, known to those skilled in the art as general brightness adaptation, which causes the observer to discount differences in over-all image brightness. The determination of the luminances of the adaptive white points used below are best done by psychophysical experiments in which the observer, adapted to the viewing environment, identifies a stimulus which appears to be achromatic and which appears to correspond to a 100% diffuse reflecting white object.

[0053] One method for transforming a set of tristim-

ulus values, $X_d Y_d Z_d$, for a given picture element of an input image, intended to be viewed in a dark surround, to a set of visually corresponding $X_n Y_n Z_n$ values for an image viewed in a normal-surround reference surround would consist of:

- 1) Computing a luminance factor β_d for the picture element, where β_d is equal to Y_d/Y_{wi} and where Y_{wi} is the luminance value for the adaptive white point of the dark-surround input viewing environment,
- 2) Defining a luminance factor β_n , where β_n is equal to Y_n/Y_{wr} and where Y_{wr} is the luminance value for the adaptive white point of the normal-surround reference viewing environment,
- 3) Computing β_n for the picture element to be equal to β_d^S , where the exponent S is an experimentally determined surround factor of less than 1.00 which corresponds to the factor to which the perceived luminance contrast would be lowered by the dark surround of the input viewing environment, and
- 4) Computing corresponding tristimulus values X_n , Y_n , Z_n for the reference viewing environment from the tristimulus values X_d , Y_d , Z_d of the input viewing environment according to the following equations:

$$Y_n = Y_d * (\beta_n / \beta_d)$$

$$X_n = X_d * (Y_n / Y_d)$$

$$Z_n = Z_d * (Y_n / Y_d)$$

[0054] If the adaptive white point of the specified input viewing environment is different in chromaticity from that of the reference viewing environment, the computed colorimetric values must be further transformed by the chromatic adaptation transform 52 to the corresponding colorimetric values for the adaptive white point of the reference viewing environment. This transformation may be performed as previously described or by using other techniques known to those skilled in the art. The values from the chromatic adaptation transform may be further transformed by the color metric conversion 54, for example, to convert from CIE XYZ units to CIE 1976 $L^*a^*b^*$ units, to form the Database Color Encoding values. The Database Color Encoding values represent the corresponding colorimetric values that would be required to match, in the viewing conditions of the reference viewing environment, the appearance of an input image, on the calibrated positive transparency medium, as that image would appear if viewed in the specified input viewing environment.

[0055] Test images 46 are additionally read by transmission scanner 18 which produces image-bearing signals corresponding to each test color. The transform apparatus 56 then creates transform 59 relating

the image-bearing signal values for the input medium colors to the determined Database Color Encoding values of the corresponding test colors.

[0056] Referring again to Figure 3, transform 59 is subsequently used in workstation 26 to transform images on positive transparency medium 16 and scanned on transmission scanner 18 to Database Color Encoding values. Consistent with the objects of this invention, all positive transparency input images so transformed are compatible with each other; moreover, they become compatible with dissimilar images, such as those on reflection medium 12, transformed according to the teaching of the first embodiment. Transforms similar to transform 59, appropriate for images on positive transparency medium 16 but for different input viewing conditions, may be derived according to the methods of this embodiment. Transforms appropriate for images on other positive transparency media and other types of media designed to be viewed in a surround condition that differs from that of the reference viewing environment, may also be derived according to the methods of this embodiment. Input images so transformed are made compatible with each other and with images produced in the first embodiment.

[0057] Fig. 5 shows, in block diagram form, a color image reproduction apparatus in accordance with a third preferred embodiment of the invention. One or more reflection image scanners 14 serve for scanning input images on one or more reflective media 12 and for producing image-bearing signals in digital form for each picture element of the reflection image being scanned. One or more transmission image scanners 18, serve for scanning input images on one or more positive transparency media 16 and for producing image-bearing signals in digital form for each picture element of the positive image being scanned. In addition, one or more transmission image scanners 22, serve for scanning negative input images on one or more negative media 20 and for producing image-bearing signals in digital form for each picture element of the negative image being scanned. A computer-based workstation 26, which receives the image-bearing signals from various scanners, transforms the input image-bearing signals into an intermediary image data encoding. The remainder of the blocks function as described for Figs. 1 and 3.

[0058] In this third embodiment, the objects of the invention which include achieving compatibility of images obtained from multiple reflection scanners and media, images obtained from multiple transmission scanners and positive transparency media, and images obtained from multiple transmission scanners and negative media are achieved by converting the image-bearing signals from reflection and transmission positive rendered images to Database Color Encoding representative of the corresponding colorimetric values that would be required to match, in the viewing conditions of the reference viewing environment, the appearance of each positive input image as that image would appear if

viewed in a specified input viewing environment and by converting image-bearing signals from negative media and other unrendered imaging media to rendered (i.e., intended for direct viewing) colorimetric values consistent with the viewing environment of the Database Color Encoding.

[0059] The present embodiment provides a method and means for generating a data-set from which transformations are derived to convert image-bearing signals from unrendered input image media, such as photographic negative media, to Database Color Encoding values.

[0060] Referring to Fig. 6, patterns of specified arrays of R, G, B exposure values or other image-forming values, chosen to adequately sample and cover the useful input range of the negative medium 20 being calibrated, are created by pattern generator 40 and are fed to image-forming apparatus 42. The image-forming apparatus produces negative test images 44, consisting of approximately 400 test colors, on one or more negative medium 20. Negative test images may be created using a variety of methods appropriate for the application. These methods would include, but would not be limited to, using an exposing apparatus such as a sensitometer, using the output device of a color imaging apparatus, or directly recording images of test objects from original test objects or reproductions of test objects on intermediary imaging media. The negative medium is then processed chemically, if necessary. The test images 44 of the negative input medium are then printed, using printer 45 and appropriate printing techniques, onto an appropriate complimentary rendering medium, such as a photographic paper, to form rendered test images 46. The colorimetric values for each test color of the rendered test images are then determined by the colorimetric measuring device 48, for the specified illuminant of the viewing environment for the rendered images of the input negative. In cases where a computational model of the complimentary rendering medium is available, the colorimetry of the rendered test colors can be determined without requiring that actual rendered test images be made and measured.

[0061] If the amount of viewing flare in the specified viewing environment for the rendered images is different from that of the reference viewing environment, the computed colorimetric values must be transformed by transform 50, using the methods previously described, to the corresponding colorimetric values for the amount of flare specified for the reference viewing environment. If the surround specified for the viewing environment of the rendered images differs from the surround of the reference viewing environment, the transformed colorimetric values are further transformed by surround-transform 51, using the methods previously described. If the adaptive white point of the specified viewing environment for the rendered images is different in chromaticity from that of the reference viewing environment, the computed colorimetric values are further transformed

by chromatic adaptation transform 52, using the methods previously described, to the corresponding colorimetric values for the adaptive white point of the reference viewing environment. The values from the chromatic adaptation transform may be further transformed by color metric conversion 54, for example to convert from CIE XYZ units to CIE 1976 L*a*b* units, to form Database Color Encoding values. The Database Color Encoding values represent the corresponding colorimetric values that would be required to match, in the viewing conditions of the reference viewing environment, the appearance of an input image, printed or otherwise rendered from the negative medium calibrated, as that rendered image would appear if viewed in a specified input viewing environment.

[0062] The negative medium test colors are additionally read by transmission scanner 22 which produces image-bearing signals corresponding to each negative test color. Transform apparatus 56 creates transform 60 that relates the image-bearing signal values for the input negative colors to the determined Database Color Encoding values of the corresponding rendered test colors.

[0063] Referring again to Figure 5, transform 60 is subsequently used in workstation 26 to transform images on negative transmission medium 20 and scanned on transmission scanner 22 to Database Color Encoding values. Consistent with the objects of this invention, negative transmission input images so transformed are compatible with each other; moreover, they are made compatible with images such as those on reflection medium 12, which have been transformed according to the teachings of the first embodiment, and they are also made compatible with images such as those on positive transparency medium 16, according to the teachings of the second embodiment. Transforms similar to transform 60, appropriate for images on negative transmission medium 20 but for different rendering media and/or rendered-input-image viewing conditions, may be derived according to the methods of this embodiment. Transforms appropriate for images on other negative transmission media, other types of unrendered media, and/or different rendered input image viewing environments may also be derived according to the methods of this embodiment. Input images so transformed are made compatible with each other and with images produced in the first and second embodiments.

[0064] Fig. 7 shows, in block diagram form, a color image reproduction apparatus in accordance with a fourth preferred embodiment of the invention. One or more reflection image scanners 14 serve for scanning input images on one or more reflection media 12 and for producing image-bearing signals in digital form for each picture element of the reflection image being scanned. One or more transmission image scanners 18, serve for scanning input images on one or more positive transparency media 16 and for producing image-bearing sig-

nals in digital form for each picture element of the positive image being scanned. One or more transmission image scanners 22, serve for scanning input images on one or more negative media 20 and for producing image-bearing signals in digital form for each picture element of the negative image being scanned. In addition, one or more electronic image sources 24, such as a charge-coupled-device (CCD) based video camera or an electronic image storage device/medium, serve to produce image-bearing signals in digital form for each picture element of a captured or stored image. The remainder of the blocks function as described for Figs. 1, 3 and 5.

[0065] In this fourth embodiment, the objects of the invention which include achieving compatibility of; images obtained from multiple reflection scanners and media, images obtained from multiple transmission scanners and positive transparency media, images obtained from multiple transmission scanners and negative media, and images obtained from various electronic imaging sources are achieved by converting the image-bearing signals from positive reflection or transmission images to a database encoding corresponding to the colorimetric values that would be required to match, in the viewing conditions of the reference viewing environment, the appearance of the positive input image as that image would appear if viewed in a specified input viewing environment, and by converting image-bearing signals from negative media and from electronic imaging sources to rendered colorimetric values consistent with the viewing environment of the Database Color Encoding.

[0066] The present embodiment provides a method and means for generating a data-set from which transformations are derived to convert image-bearing signals corresponding to unrendered input images, such as signals or data obtained from some types of electronic imaging source to the Database Color Encoding values.

[0067] Referring to Fig. 8, patterns of specified arrays of R, G, B or other image-forming values, chosen to adequately sample and cover the useful range of values representative of those produced by the electronic imaging source being calibrated, are created by pattern generator 40 and are provided to signal-forming apparatus 68. The image-forming apparatus produces signals which are provided to image-rendering apparatus/medium 66 to produce one or more rendered test images 64, consisting of approximately 400 test colors. The image-rendering apparatus/medium 66 may be a thermal printer or other device to which the electronic image data might normally be sent. The test images 64 are processed chemically or by other means appropriate for the specific medium to produce the test colors. The image-rendering apparatus/medium 66 could also be an electronic display device, such as a video monitor. The colorimetric values for each test color of the rendered test images are then determined by the colorimetric measuring device 48, for the speci-

fied illuminant of the viewing environment for the input medium. In cases where a computational model of the image-rendering apparatus/medium is available, the colorimetry of the rendered test colors can be determined without requiring that actual rendered images be made and measured.

[0068] If the amount of viewing flare of the specified viewing environment for the images rendered from the input electronic imaging source is different from that of the reference viewing environment, the computed colorimetric values are transformed by viewing-flare transform 50 to the corresponding colorimetric values for the amount of flare specified for the reference viewing environment, using the previously described methods. If the surround specified for the viewing environment of the images rendered from the input electronic imaging source differs from the surround of the reference viewing environment, the transformed colorimetric values are further transformed by surround-transform 51, using the methods previously described. If the adaptive white point of the specified viewing environment of the images rendered from the input electronic imaging source is different in chromaticity from that of the reference viewing environment, the computed colorimetric values are further transformed by chromatic adaptation transform 52 to the corresponding colorimetric values for the adaptive white point of the reference viewing environment, using the previously described methods or other techniques known to those skilled in the art. The values from the chromatic adaptation transform may be further transformed by color metric conversion 54, for example to convert from CIE XYZ units to CIE 1976 L*a*b* units, to form Database Color Encoding values. The Database Color Encoding values represent the corresponding colorimetric values that would be required to match, in the viewing conditions of the reference viewing environment, the appearance of an input image, rendered from the electronic imaging source being calibrated, as that image would appear if viewed in the specified rendered-image viewing environment.

[0069] Image-bearing signals from signal-forming apparatus 68 are additionally provided to transform apparatus 56 which creates transform 61 that relates image-bearing signal values, corresponding to those produced by the electronic imaging source being calibrated, to the determined Database Color Encoding values of the corresponding rendered test colors.

Referring again to Figure 7, transform 61 is subsequently used in workstation 26 to transform images from electronic imaging source 24 to Database Color Encoding values. Consistent with the objects of this invention, images from electronic imaging sources so transformed are compatible with each other; moreover, they are made compatible with images such as those on reflection medium 12, which have been transformed according to the teachings of the first embodiment, they are made compatible with images such as those on positive transparency medium 16 transformed according to the

teaching of the second embodiment, and they are made compatible with images such as those on negative transmission medium 20, transformed according to the teaching of the third embodiment. Transforms similar to transform 61, appropriate for images from electronic imaging source 24 but for different rendering devices/media and/or rendered-input-image viewing conditions, may be derived according to the methods of this embodiment. Transforms appropriate for images from other electronic imaging sources and/or other input image viewing environments may also be derived according to the methods of this embodiment. Input images so transformed are made compatible with each other and with images produced in the first, second, and third embodiments.

[0070] Each image on each type of input medium or source calibrated according to these four embodiments will yield Database Color Encoding values representative of the corresponding colorimetric values that would be required to match, in the viewing conditions of the reference viewing environment associated with the Database Color Encoding, the appearance of a rendered input image, as that image would appear if viewed in a specified input viewing environment. In many cases, uncalibrated inputs may also be used with transformations derived for similar types of inputs, and the results would generally be satisfactory.

[0071] The operations required to perform the input transformations of this invention may consist of a sequence of matrix operations, 1-dimensional look-up tables, polynomial or other mathematical expressions, 3-dimensional look-up tables, or other computational techniques.

[0072] Again referring to Figure 7, the present invention provides a method and means for transforming Database Color Encoding values, which may have been obtained from any of the described types of input sources, to output values or signals. When said output values or signals are provided to appropriately calibrated image-writing or image-forming devices, such as output device 34 or video display 30, images will be formed whose appearance will match, for any specified output viewing environment, the appearance of the image as described by the colorimetric values and reference viewing environment of the Database Color Encoding. The specified output environment, which may differ from the reference viewing environment of the database, may correspond to an actual output viewing environment to be used or to the viewing environment generally associated with the type of output imaging device/medium. As with the specified input viewing environment, the specified output viewing environment must be defined in terms of its surround, adaptive white point, viewing flare, and illumination spectral power distribution.

[0073] The present invention provides a method and means for generating a data set from which transformations may be derived to convert Database Color

Encoding values to the CIE standard colorimetric data values required to match, in a specified output viewing environment, the appearance corresponding to the database colorimetric values and the database viewing environment.

[0074] Referring now to Fig. 9, specified arrays of Database Color Encoding values are provided by pattern generator 40 to transform apparatus 56 and to viewing flare transform 50. If the amount of viewing flare of the specified output viewing environment is different from that of the reference viewing environment, the specified Database Color Encoding values are transformed by viewing-flare transform 50 to the corresponding colorimetric values for the amount of flare specified for the output viewing environment, using the previously described methods or other techniques known to those skilled in the art. If the surround specified for the output viewing environment differs from the surround of the reference viewing environment, the transformed colorimetric values are further transformed by surround-transform 51 to the corresponding colorimetric values for the surround of the output viewing environment, using the methods previously described or other techniques known to those skilled in the art. If the adaptive white point of the specified output viewing is different in chromaticity from that of the reference viewing environment, the values from transform 51 are further transformed by chromatic adaptation transform 52 to the corresponding colorimetric values for the adaptive white point of the output viewing environment, using the previously described methods or other techniques known to those skilled in the art. The transformed values represent the corresponding CIE standard colorimetric values that would be required to match, in the viewing conditions of the output viewing environment, the appearance of an image as that image would appear if viewed in the reference viewing environment. The values from transform 52 may be further transformed by color metric conversion 54 to the particular CIE standard colorimetric units to be used for the calibration of the particular output device/medium. Transform apparatus 56 then creates transform 72 relating the Database Color Encoding values to the CIE standard color values required to match, in the specified output viewing environment, the appearance corresponding to the database colorimetric values and the database viewing environment. Likewise transform 76 may be derived for video display 30 in a similar fashion.

[0075] The present invention provides a method and means for generating a calibration data set from which transformations may be derived to convert CIE standard colorimetric data values to output device drive values required to produce the colorimetric values for any of a plurality of image-forming media and/or devices.

[0076] Referring to Fig. 10, specified arrays of R, G, B or other output image-forming values, chosen to adequately sample and cover the useful range of drive val-

ues for the output device/medium being calibrated, are created by pattern generator 40 and are provided to signal-forming apparatus 62. The image-forming apparatus produces signals which are provided to an output image-forming device/medium 70 to produce one or more output test images 64, consisting of approximately 400 test colors. The output imaging medium is processed chemically or by other means appropriate for the specific medium to produce output test images. Output image-forming device/medium 70 could also be an electronic display device, such as a video monitor. CIE standard colorimetric values for each test color of the output test images are then determined by the colorimetric measuring device 48, for the specified illuminant of the viewing environment for the output device/medium. Transform apparatus 56 is then used to develop transform 74, which is used to transform colorimetric values to the device drive values which would produce image areas with those colorimetric values on the output device/medium. Likewise transform 78 may be derived for video display 30 in a similar fashion.

[0077] Referring again to Figure 7, transforms 72 and 74 are used in combination in workstation 26 to provide the output device drive values required to produce colorimetric values, on a specified output device, such as output device 34, and medium, such as output medium 36, and for a specified output viewing environment, which will produce a visual match corresponding to the colorimetric values specified in the reference viewing environment of the Database Color Encoding. In some cases, the desired colorimetric values may correspond to colors that are outside of the gamut of colors that can actually be produced by the specified output device/medium. In such cases, the out-of-gamut colorimetric values may be transformed by transform 73 into in-gamut colorimetric values using any of a number of gamut-mapping techniques known to those skilled in the art. In some applications, it may be operationally convenient to combine the functions of transforms 72, 73, and 74 into a single transform.

[0078] Similarly, transforms 76 and 78 are used to provide output drive values for video display 30. Again, in some cases, the desired colorimetric values may correspond to colors that are outside of the gamut of colors that can actually be produced by the specified video display. In such cases, the out-of-gamut colorimetric values may be transformed by transform 77 into in-gamut colorimetric values. In addition, in cases where video display 30 is used to preview the appearance of images to be produced on another output device/medium, transform 77 may include additional gamut-mapping consistent with the gamut limitations of the particular output device/medium. In some applications, it may be operationally convenient to combine the functions of transforms 76, 77, and 78 into a single transform.

[0079] The operations required to perform the output transformations of this invention may consist of a sequence of matrix operations, 1-dimensional look-up

tables, polynomial or other mathematical expressions, 3-dimensional look-up tables, or other computational techniques.

[0080] Referring to the map of Figure 11 and Figures 11a, 11b, and 11c arranged according to the map, a color image reproduction system in accordance with a fifth preferred embodiment of the invention is shown. In this embodiment, the methods and means of the previous embodiments are combined with additional related methods and means to form a comprehensive color-imaging and color-management system.

[0081] Figure 11a shows each of the input types for this embodiment along with the image-processing operations that would be required to bring each input into the reference Database Color Encoding.

[0082] Unrendered images from electronic sources 112, such as the KODAK Photo CD System and the KODAK Premier Image Enhancement System, are first rendered, in accordance with the teachings of this present invention, in order to be compatible with the definition of the reference Database Color Encoding. This is accomplished by user-selected rendering options provided by the Rendering Transformations 114, derived according to the techniques of the fourth preferred embodiment of the present invention. The rendering options may be general, such as "reflection print", or "projectable transparency" or they may be more specific, referring to a specific rendering device and/or medium. The rendering options may also include an idealized computational rendering that would produce images that are compatible with other database images while retaining the full dynamic range and color gamut of these input sources. A "no rendering" option may also be included. This option could be used in certain cases, such as for merging two Photo CD images to form a composite image that could then be written to a Photo CD-compatible file. The output from the Rendering Transformations 114 is expressed in terms of the reference viewing environment. Any required metric conversion, i.e., a conversion to the colorimetric units of the Database Color Encoding, can then be performed by Color Metric Conversion 116.

[0083] Original artwork (such as paintings, drawings, etc.), and photographic and other reflection prints 118 already exist as rendered images. The colorimetry for such images are measured by calibrated reflection Colorimetric Scanner 120. A colorimetric scanner is defined here to mean that the actual physical spectral responsivities of the scanner correspond to any given set of CIE color-matching functions. For an input material used in a viewing environment that is different in viewing flare or illuminant chromaticities from the reference viewing environment, the corresponding colorimetry for the reference viewing environment must be determined. This is accomplished in Viewing Transform 122 according to the techniques described in the first embodiment of this invention. The output from the transform 122 may be in terms of any colorimetric units, as

any required metric conversion can be performed by Color Metric Conversion 124.

[0084] Photographic and other transparencies 126, with any imaging dye set, are also rendered images. The colorimetry for such images can be measured by calibrated transmission Colorimetric Scanner 128. Again, a colorimetric scanner is defined here to mean that the actual physical spectral responsivities of the scanner correspond to any given set of CIE color-matching functions. For a transparency material designed for use in a viewing environment, such as darkened room projection, that is different from the reference viewing environment, the corresponding colorimetry for the reference viewing environment must be determined. This is accomplished in Viewing Transform 130, which also corrects for differences in input and reference viewing flare and adaptive white point, according to the techniques described in the second embodiment of this invention. The output from transform 130 may be in terms of any colorimetric units, as any required metric conversion can be performed by Color Metric Conversion 132.

[0085] Photographic and other reflection prints 134 of known imaging dye sets can be measured by a calibrated reflection RGB Scanner 136. The RGB output of the scanner can then be converted to colorimetry by Transform to Colorimetry 138 using the techniques of the first preferred embodiment. Each scanner with different RGB responsivities and each product with a different imaging dye set would require a different transform. For an input material used in a viewing environment that is different in viewing flare or illuminant chromaticities from the reference viewing environment, the corresponding colorimetry for the reference viewing environment must be determined. This is accomplished in Viewing Transform 140 according to the techniques described in the first embodiment of this invention. The output from transform 140 may be in terms of any colorimetric units, as any required metric conversion can be performed by Color Metric Conversion 142.

[0086] Photographic and other transparencies 144 of known imaging dye sets can be measured by a calibrated transmission RGB Scanner 146. The RGB output of the scanner can then be converted to colorimetry by Transform to Colorimetry 148 using the techniques of the second preferred embodiment. Each scanner with different RGB responsivities and each product with a different imaging dye set would require a different transform. For a transparency material designed for use in a viewing environment that is different from the reference viewing environment (such as darkened-room projection), the corresponding colorimetry for the reference viewing environment must be determined. This is accomplished in Viewing Transform 150, which also corrects for differences in input and reference viewing flare and adaptive white point, using the techniques of the second preferred embodiment. The output from the transform 150 may be in terms of any colorimetric units,

as any required metric conversion can be performed by Color Metric Conversion 152.

[0087] Photographic and other negatives 154 of known imaging dye sets can be measured by a calibrated transmission RGB Scanner 156. Negatives must be rendered in order to be compatible with the reference Database Color Encoding. This is accomplished by user-selected rendering options provided by the Rendering Transformations 158 using the techniques of the third preferred embodiment of this invention. Each scanner with different RGB responsivities and each product with a different imaging dye set would require a different set of transforms. The output from the selected rendering transform 158 may be in terms of any colorimetric units, as any required metric conversion can be performed by Color Metric Conversion 160.

[0088] Video signals from a video capture device 162, such as a video camera, correspond to unrendered images that must be rendered in order to be compatible with the reference encoding. This is accomplished by the user-selected rendering options provided by the Rendering Transformations 164 using the techniques of the fourth preferred embodiment of this invention. The output from the selected rendering transform 164 may be in terms of any colorimetric units, as any required metric conversion can be performed by Color Metric Conversion 166.

[0089] RGB code values or drive values corresponding to an image that appears on a device such as video monitor 168 may be entered directly to the system. These code values carry an implied rendering, the colorimetry for which can be determined by Transform to Colorimetry 170 which contains a computational model of the device relating code or drive values to reproduced colorimetry which may be derived using the colorimetric device/medium calibration techniques previously described. Viewing Transform 172 incorporates chromatic adaptation transforms, surround transforms, flare corrections as required to account for any differences between the actual viewing conditions for the device and those of the reference environment using the techniques described in the second preferred embodiment. The output from transform 172 may be in terms of any colorimetric units, as any required metric conversion can be performed by Color Metric Conversion 174.

[0090] Colorimetrically-specified values 176, such as those that may be specified for a background, bar-chart, product logo, text color, etc., may be entered directly to the color imaging system of the present embodiment. Entered colorimetric values may also correspond to image files previously written by this system or to any other colorimetrically-specified image files. Viewing Transform 178 incorporates chromatic adaptation transforms, surround transforms, and flare corrections as required to account for any differences between the viewing conditions corresponding to the specified colorimetry and those of the reference environment

using the techniques described in the second preferred embodiment. The entered and transformed values may be in terms of any colorimetric units, such as CIE XYZ, CIELAB, Munsell, Pantone, etc., as any required metric conversion can be performed by Color Metric Conversion 180.

[0091] CMYK (cyan, magenta, yellow, black) reflection data 182 for defined imaging colorant sets can also be entered into the system. The CMYK data are converted to colorimetry by Transform to Colorimetry 184, which may be derived using techniques, such as the Neugebauer equations, known to those skilled in the graphic arts. Each different imaging dye set would require a different transform. For input data corresponding to a viewing environment that is different in viewing flare or illuminant chromaticities from the reference viewing environment, the corresponding colorimetry for the reference viewing environment must be determined. This is accomplished in Viewing Transform 186 according to the techniques described in the first embodiment of this invention. The output from the transform 186 may be in any colorimetric units, as any required metric conversion can be performed by Color Metric Conversion 188.

[0092] By the use of these techniques, all input images and data are converted to a uniquely defined Database Color Encoding 190. All input images that were already rendered when they came into the system have been encoded in a way that retains their original rendering and which encodes that rendering in colorimetric terms defined as that required to produce, in the reference viewing environment, the color appearance of the image as it would have appeared had it been viewed in its specified input viewing environment. All images that were not already rendered when they came into the system have been rendered by user-defined rendering transforms and are encoded in a way that retains the appearance of that selected rendering. The image Database Color Encoding 190 retains the appearance of the rendered images, and the common reference viewing environment encoding allows for the intermixing of partial images and for the storage and exchange of images to-and-from disparate devices and media without requiring a knowledge of the original source of the image.

[0093] Images so encoded can be modified by User-defined Modifications 194. These modifications, which may be provided in a computer application program, might include color and tone scale modifications, special effects, etc. These image modifications may also be applied anywhere along the system data paths preceding the Database Color Encoding 190. For many forms of images, these modifications might be applied immediately following the Color Metric Conversions. For certain modifications of other types of images, such as color and density corrections to some forms of unrendered images, it is advantageous to modify the image data before the Rendering Transforms (114, 158 and

164) are applied.

[0094] Images can be further modified using any of a plurality of Gamut Mapping Strategies, indicated by 196 and 198. The specific gamut mapping transforms corresponding to these strategies would generally be dependent on the gamut capabilities and limitations of a selected output device/medium/viewing environment. Multiple gamut-mapping strategies may occur simultaneously, as it may be desired to use more than one strategy on a single page (for pictorial and presentation graphic images, for example). The result of the user-defined modifications and the gamut mapping transforms is the Modified Colorimetry 200, which is still expressed in terms of the reference viewing environment.

[0095] Modified data are then sent to any of a plurality of output devices (Figure 11c). Video previewing on calibrated Video Display 208 is accomplished by first transforming the image data from 200 by Viewing Environment Transformation for Video Display Transform 202 which incorporates output transformation techniques previously described and which are illustrated in Figures 9 and 10. This transform includes chromatic adaptation transforms, surround transforms, and flare corrections as required to account for any differences between the actual viewing conditions for the video display and those of the reference environment. If the purpose of the video display is to preview an image to be subsequently produced by another output device/medium, an additional video-related gamut mapping is performed by Gamut Mapping for Video Preview Transform 204, derived so as to appropriately adjust any colors that are within the gamut of the specified output device/medium but outside of the gamut of the video display in order to obtain an optimum video preview of the image. The code values (video drive signals) for the display are then determined using Transformation of Colorimetry to Video Code Values 206, developed using the previously described output calibration techniques.

[0096] Reflection prints are made by sending image data to a colorimetrically-calibrated Reflection Print Writer 216. Image data from 200 to be sent for output are first transformed by viewing Environment Transformation for Reflection Print 210. This transform, derived using the techniques of the first preferred embodiment of the present invention, incorporate chromatic adaptation transforms and flare corrections required to account for any differences between the actual viewing conditions for the output print and those of the reference environment. The code values (writer drive values) for the writer are determined using Transformation of Colorimetry to Writer Code Values 214 using the previously described output calibration techniques.

[0097] Transparencies are made by sending image data to a colorimetrically-calibrated Transparency Writer 224, calibrated using the previously described output calibration techniques. Image data are first transformed by Viewing Transformation for Transparency

Transform 218. This transform, derived using the techniques of the second preferred embodiment of the present invention, incorporates chromatic adaptation transforms, surround transforms, and flare corrections as required to account for any differences between the actual viewing conditions for the transparency and those of the reference environment. The code values (writer drive values) for the writer are determined using Transformation of Colorimetry to Writer-Code Values 222, determined according to the previously described output device calibration techniques.

[0098] Photographic negatives are made by sending image data to a calibrated Negative-film Writer 232. Image data are first transformed by Viewing Transformation for Rendered Output 226. This transform, derived using previously described techniques, incorporates chromatic adaptation transforms, surround transforms, and flare corrections as required to account for any differences between the actual viewing conditions for the rendered output image and those of the reference environment. Transformed data are then further transformed by Transformation of Colorimetry to Printing Density Values 228. This transform incorporates a model of the photographic paper or other complementary medium onto which the writer-produced negative will be printed. This model relates desired output medium colorimetry to the printing density values, i.e., the negative log of the factor by which the negative attenuates the exposure to the photographic printing medium, required to produce that colorimetry. Models relating print material colorimetry to printing densities values are well known to those skilled in the photographic arts. The drive values for the writer are determined using Transformation of Printing Densities to Writer Code Values 230. This transformation is derived from a printing-density model of the output negative and the calibrated writer. Alternatively, viewing-environment-transformed colorimetric values could be transformed directly to device drive values using the techniques of the third preferred embodiment of the present invention.

[0099] Black and white separations for graphic arts and other applications are made by sending image data to calibrated B & W Film Writer 240. Image data are first transformed by Viewing Transformation for Rendered Output 234. This transform, derived using previously described techniques, incorporates chromatic adaptation transforms, surround transforms, and flare corrections as required to account for any differences between the actual viewing conditions for the rendered output image produced from the separations and those of the reference environment. Transformed data are then further transformed by Transformation of Colorimetry to Percent Dot Values 236, derived using techniques known to those skilled in the graphic arts. This transform incorporates a model of the actual process in which the writer-produced separations will be used. The code values (writer drive values) for the writer are determined using Transformation of Percent Dot Values to

Writer Code Values 238, again using techniques known to those skilled in the graphic arts.

[0100] The system provides for writing image data directly to a data file for storage or for transfer to other systems. The data may be in the form of Colorimetric Units 246, provided by Viewing Environment Transformation for Output 242 and Color Metric Space Conversion 244. The data may also be in the form of Device-Specific units 252, such as device drive values, colorant amounts, RGB intensities, etc., provided by Viewing Environment Transformation for Output 248 and Transformation to Device-Specific Units 250, which may be formed using the colorimetric calibration techniques described in the fourth preferred embodiment of this invention.

Parts List

[0101]

- | | |
|----|--|
| 12 | Reflection medium |
| 14 | Image/reflection scanner |
| 16 | Transparency media |
| 18 | Image scanner/transmission image scanner |
| 20 | Negative media/medium |
| 22 | Transmission image scanner |
| 24 | Electronic imaging source |
| 26 | Computer-based workstation |
| 28 | Storage devices |
| 30 | Video display |
| 32 | Control apparatus |
| 34 | Output device |
| 36 | Image-receptive media |
| 40 | Pattern generator |
| 42 | Image-forming apparatus |
| 44 | Negative test images |
| 45 | Printer |
| 46 | Test images |
| 48 | Measuring device |

50	Viewing-flare transform	136	RGB scanner
51	Surround-transform	138	Transform to colorimetry
52	Chromatic adaptation transform	5 140	Viewing transform
53	Transform	142	Color metric conversion
54	Color metric conversion	144	Transparencies
56	Transform apparatus	10 146	RGB scanner
58	Transform	148	Transform to colorimetry
59	Transform	15 150	Viewing transform
60	Transform	152	Color metric conversion
61	Transform	154	Negatives
62	Signal-forming apparatus	20 156	RGB scanner
64	Test images	158	Rendering transforms
66	Image-rendering apparatus/medium	25 160	Color metric conversion
68	Signal-forming apparatus	162	Video capture device
70	Output image-forming device/medium	164	Rendering transformations
72	Transform	30 166	Color metric conversion
74	Transform	168	Video monitor
112	Electronic sources	35 170	Transform to colorimetry
114	Rendering transforms	172	Viewing transform
116	Color metric conversion	174	Color metric conversion
118	Reflection prints	40 176	Colorimetrically-specified values
120	Colorimetric Scanner	178	Viewing transform
122	Viewing transform	45 180	Color metric conversion
124	Color metric conversion	182	Reflection data
126	Photograph and other transparencies	184	Transform to colorimetry
128	Colorimetric scanner	50 186	Viewing transform
130	Viewing transform	188	Color space conversion
132	Color metric conversion	55 190	Database Color Encoding
134	Reflection prints	194	User-defined modifications

196	Gamut mapping strategies		246	Output file in colorimetric units
198	Gamut mapping strategies		248	Viewing environment transformation for output
200	Modified colorimetry	5	250	Transformation to device-specific units
202	Viewing environment transformation for video display		252	Output file device-specific units
204	Gamut mapping for video preview	10		
206	Transformation of colorimetry to video code values			
208	Video display	15		
210	Viewing environment transformation for reflection print			
214	Transformation of colorimetry to writer code values	20		
216	Reflection print writer/medium			
218	Viewing environment transformation for transparency	25		
222	Transformation of colorimetry to writer code values	30		
224	Transparency writer/medium			
226	Viewing environment transformation for rendered output	35		
228	Transformation of colorimetry to printing densities	40		
230	Transformation of printing densities to writer code values	45		
232	Negative writer/medium			
234	Viewing environment transformation for rendered output	50		
236	Transformation of colorimetry to percent dot values	55		
238	Transformation of percent dot values to writer code values			
240	B & W Film writer/medium			
242	Viewing environment transformation for output			
244	Color metric conversion			

Figures Associated With Claims	
Claim #	Associated Figures
1	1, 3, 5, 7 and 11
2	1, 3, 5, 7 and 11a
3	1, 3, 5, 7 and 11a
4	1, 3, 5, 7 and 11c
5	1, 3, 5, 7 and 11c
6	1, 3, 5, 7 and 11a
7	5, 7 and 11a
8	5, 7 and 11a
9	5, 7 and 11c
10	5, 7 and 11c
11	4
12	1, 3, 5, 7 and 11a
13	6
14	6
15	6
16	6
17	6
18	8
19	7
20	9
21	9 and 10
22	11a
23	11a

Claims

1. A method for forming a transform (59) for transforming image signals derived from input images formed by an imaging medium (12, 16, 20, 24) to intermediate data base color values corresponding to the colorimetric values that would be required to match, in the viewing condition of a reference viewing environment, the appearance of the input image as it would appear if viewed in a specific input viewing

environment, comprising the steps of

- a) specifying the input viewing environment in terms of its illuminant spectral power distribution, amount of viewing flare light, surround, and adaptive white point chromaticities; 5
 - b) specifying the reference viewing environment in terms of its amount of viewing flare light, surround, and adaptive white point chromaticities; 10
 - c) specifying patterns of image-forming values for producing colors which adequately sample and cover the useful color-range of said imaging medium (12, 16, 20, 24); 15
 - d) forming test colors (46) with said imaging medium (12, 16, 20, 24) using said image-forming values; 20
 - e) determining colorimetric values (48) from said test colors (46) and the input viewing environment illuminant spectral power distribution; 25
 - f) adjusting said colorimetric values (50) in accordance with the difference in the amounts of viewing flare light specified for the input viewing environment and the reference viewing environment to form flare-adjusted colorimetric values; 30
 - g) adjusting said flare-adjusted colorimetric values (52) in accordance with the difference between the adaptive white point chromaticities specified for the input viewing environment and the reference viewing environment to form chromatic adapted colorimetric values; 35
 - h) sensing said test colors (46) using an image-sensing means (14, 18, 23) to form test color image signals; and 40
 - i) forming the transform (58) by relating said test color image signals to corresponding chromatic-adapted colorimetric values. 45
2. The method according to claim 1 further comprising the step of: 50
 - k) applying said transform (58) to the image signals to form intermediate database color values.
 3. The method according to claim 1, further comprising the step of further adjusting said flare-adjusted colorimetric values in accordance with the difference in the surround specified for the input viewing 55

environment and the reference viewing environment.

4. A digital color image processing system of the type having means for correcting an input image signal for lighting conditions) characterized by a transform means (58) for transforming the input image signal to an intermediary database color encoding representing the colorimetric values that would be required to match, in the viewing conditions of a reference viewing environment, the appearance of the input image as it would appear if viewed in a specified input viewing environment.

15 Patentansprüche

1. Verfahren zum Erzeugen einer Transformation (58, 59, 60, 61) zum Umwandeln von Bildsignalen, die von Eingabebildern abgeleitet sind, welche durch ein Abbildungsmedium (12, 16, 20, 24) erzeugt wurden, in intermediäre Datenbank-Farbwerte, die den kolorimetrischen Werten entsprechen, welche benötigt würden, um unter Betrachtungsbedingungen einer Referenzbetrachtungsumgebung das Aussehen eines Eingabebildes so anzupassen, wie es erscheinen würde, wenn es in einer speziellen Eingabebetrachtungsumgebung betrachtet würde, wobei das Verfahren folgende Schritte umfaßt:

- a) Spezifizieren der Eingabebetrachtungsumgebung bezüglich ihrer spektralen Strahlungsdichteverteilung des Lichts, der Menge des Betrachtungssteulichts, des Umfelds und der adaptiven Weißpunkt-Farbverteilung;
- b) Spezifizieren der Referenzbetrachtungsumgebung bezüglich ihrer Menge des Betrachtungssteulichts, des Umfelds und der adaptiven Weißpunkt-Farbverteilung;
- c) Spezifizieren von Mustern von Bilderzeugungswerten zum Erzeugen von Farben, die als angemessene Testwerte den nutzbaren Farbbereich des Abbildungsmediums (12, 16, 20, 24) abdecken;
- d) Erzeugen von Testfarben (46) mittels des Abbildungsmediums (12, 16, 20, 24) unter Verwendung der Bilderzeugungswerte;
- e) Bestimmen kolorimetrischer Werte (48) aus den Testfarben (46) und der spektralen Strahlungsdichteverteilung des Lichts der Eingabebetrachtungsumgebung;
- f) Angleichen (50) der kolorimetrischen Werte (48) entsprechend der Differenz der Mengen an Betrachtungssteulicht, das für die Eingabebetrachtungsumgebung und die Referenzbetrachtungsumgebung spezifiziert wurde, um steulichtangepaßte, kolorimetrische Werte zu erzeugen;
- g) Angleichen der steulichtangepaßten kolori-

metrischen Werte (52) entsprechend der Differenz zwischen den adaptiven Weißpunkt-Farbverteilungen, die für die Eingabebetrachtungsumgebung und die Referenzbetrachtungsumgebung spezifiziert wurden, um chromatisch angepaßte, kolorimetrische Werte zu erzeugen;

h) Abtasten der Testfarben (46) unter Verwendung von Bildabtastmitteln (14, 18, 22), um Bildsignale der Testfarben zu erzeugen; und

i) Erzeugen der Transformation (58, 59, 60, 61), indem man die Testfarben-Bildsignale mit den entsprechenden chromatisch angepaßten, kolorimetrischen Werten in Beziehung setzt.

2. Verfahren nach Anspruch 1 mit folgendem weiteren Schritt:

k) Beaufschlagen der Bildsignale mit der Transformation (58, 59, 60, 61), um intermediäre Datenbank-Farbwerte zu erzeugen.

3. Verfahren nach Anspruch 1 mit folgendem zusätzlichen Schritt:

- weiteres Angleichen der streulichtangepaßten, kolorimetrischen Werte entsprechend der Differenz des für die Eingabebetrachtungsumgebung und die Referenzbetrachtungsumgebung spezifizierten Umfelds.

4. Digitales Farbbild-Verarbeitungssystem mit Mitteln zum Korrigieren eines Eingabebildsignals bezüglich Beleuchtungsbedingungen, gekennzeichnet durch ein Transformationsmittel (58) zum Umwandeln des Eingabebildsignals in eine intermediäre Datenbank-Farbkodierung, welche die kolorimetrischen Werte kennzeichnet, die benötigt würden, um unter Betrachtungsbedingungen einer Referenzbetrachtungsumgebung das Aussehen eines Eingabebildes so anzupassen, wie es erscheinen würde, wenn es in einer speziellen Eingabebetrachtungsumgebung betrachtet würde.

Revendications

1. Procédé pour former une transformation (59) afin de transformer des signaux image dérivés d'images d'entrée formées par un support de formation d'image (12, 16, 20, 24) en valeurs de couleur de base de données intermédiaires correspondant aux valeurs colorimétriques qui seraient nécessaires pour correspondre, dans les conditions d'examen d'un environnement d'examen de référence, à l'apparence de l'image entrée, ainsi qu'elle apparaîtrait si elle était examinée dans un environnement d'examen d'entrée spécifique, comprenant les étapes consistant à :

a) spécifier l'environnement d'examen d'entrée en termes de distribution de puissance de spectre d'éclairage, de quantité de lumière diffuse d'examen, d'entourage, et de chromaticités adaptatives de points blancs ;

b) spécifier l'environnement d'examen de référence en termes de quantité de lumière diffuse d'examen, d'entourage et de chromaticités adaptatives de points blancs ;

c) spécifier des trames de valeurs de formation d'image pour produire des couleurs qui échantillonnent de façon adéquate et couvrent la gamme utile de couleurs dudit support de formation d'image (12, 16, 20, 24) ;

d) former des couleurs de test (46) avec ledit support de formation d'image (12, 16, 20, 24) en utilisant lesdites valeurs de formation d'image ;

e) déterminer des valeurs colorimétriques (48) à partir desdites couleurs de test (46) et la distribution de puissance de spectre d'éclairage de l'environnement d'examen d'entrée ;

f) ajuster lesdites valeurs colorimétriques (50) conformément à la différence entre les quantités de lumière diffuse d'examen spécifiées pour l'environnement d'examen d'entrée et l'environnement d'examen de référence afin de former des valeurs colorimétriques ajustées en fonction de la lumière diffuse ;

g) ajuster lesdites valeurs colorimétriques ajustées en fonction de la lumière diffuse (52) conformément à la différence entre les chromaticités adaptatives de points blancs spécifiées pour l'environnement d'examen d'entrée et l'environnement d'examen de référence afin de former des valeurs colorimétriques adaptées de façon chromatique ;

h) analyser lesdites couleurs de test (46) en utilisant un moyen d'analyse d'image (14, 18, 23) afin de former des signaux image de couleur de test ; et

i) former la transformation (58) en reliant lesdits signaux image de couleur de test aux valeurs colorimétriques adaptées de façon chromatique correspondantes.

2. Procédé selon la revendication 1, comprenant en outre l'étape consistant à :

k) appliquer ladite transformation (58) aux signaux image afin de former des valeurs de couleur de base de données intermédiaires.

3. Procédé selon la revendication 1, comprenant en outre l'étape d'ajustement ultérieur desdites valeurs colorimétriques ajustées pour la lumière diffuse conformément à la différence dans l'entourage spécifié pour l'environnement d'examen d'entrée et

l'environnement d'examen de référence.

4. Système de traitement d'image en couleur numérique du type comportant un moyen pour corriger un signal image d'entrée pour les conditions de lumière, caractérisé par un moyen de transformation (58) pour transformer le signal image d'entrée en un codage de couleur de base de données intermédiaires représentant les valeurs colorimétriques qui seraient nécessaires pour correspondre, dans les conditions d'examen de l'environnement d'examen de référence, à l'apparence de l'image entrée ainsi qu'elle apparaîtrait si elle était examinée dans un environnement d'examen d'entrée spécifié.

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FIGURE 1

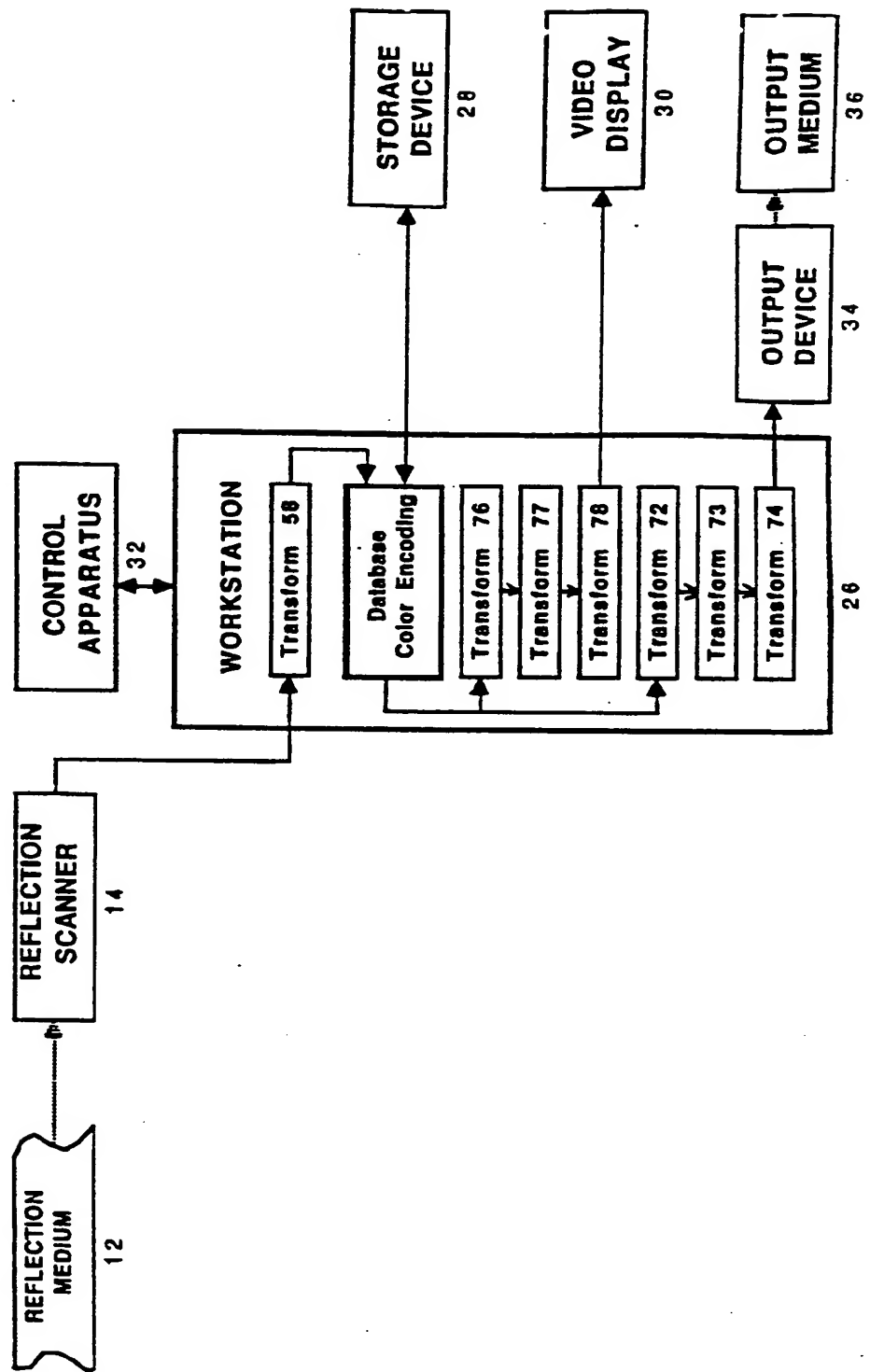


FIGURE 2

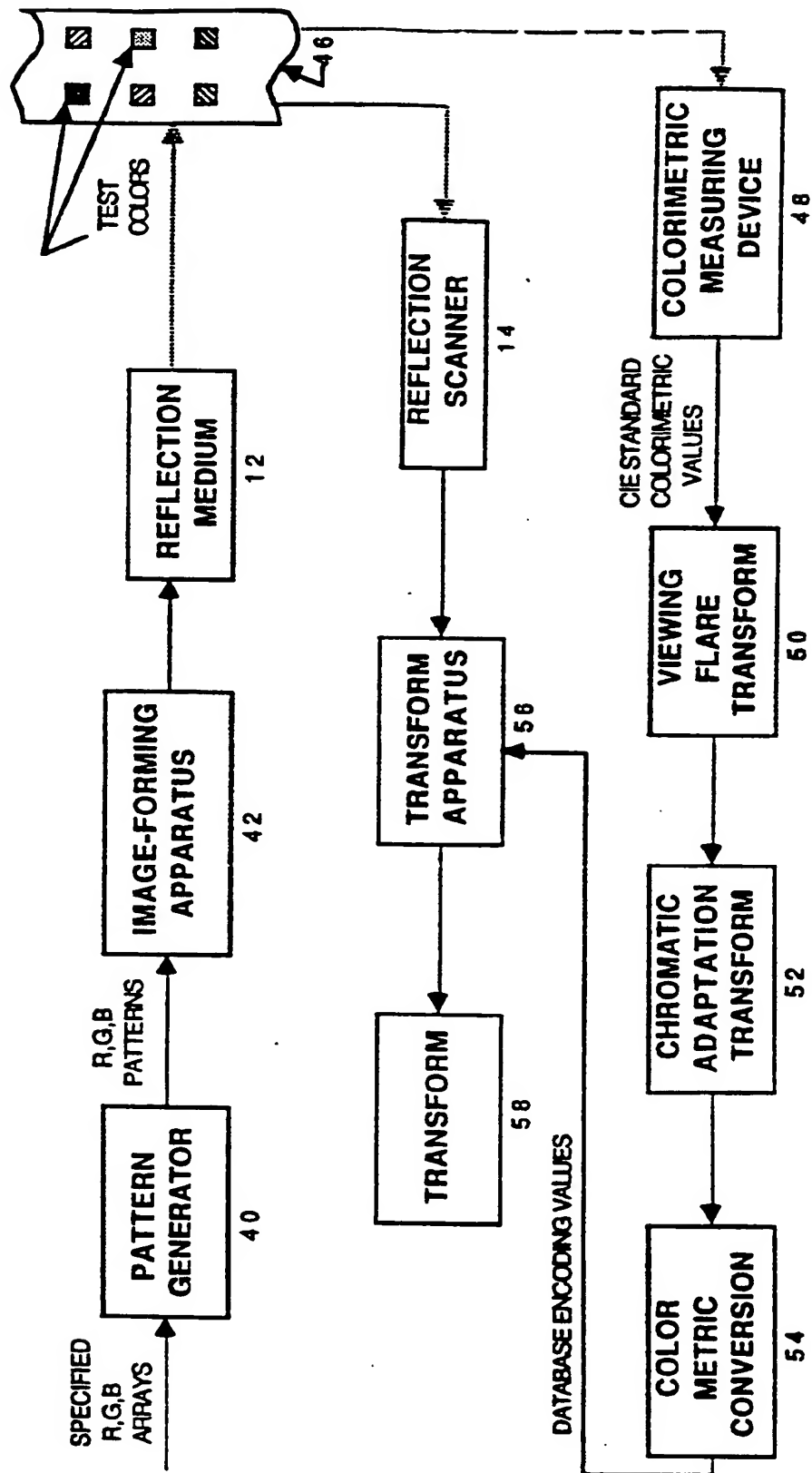


FIGURE 3

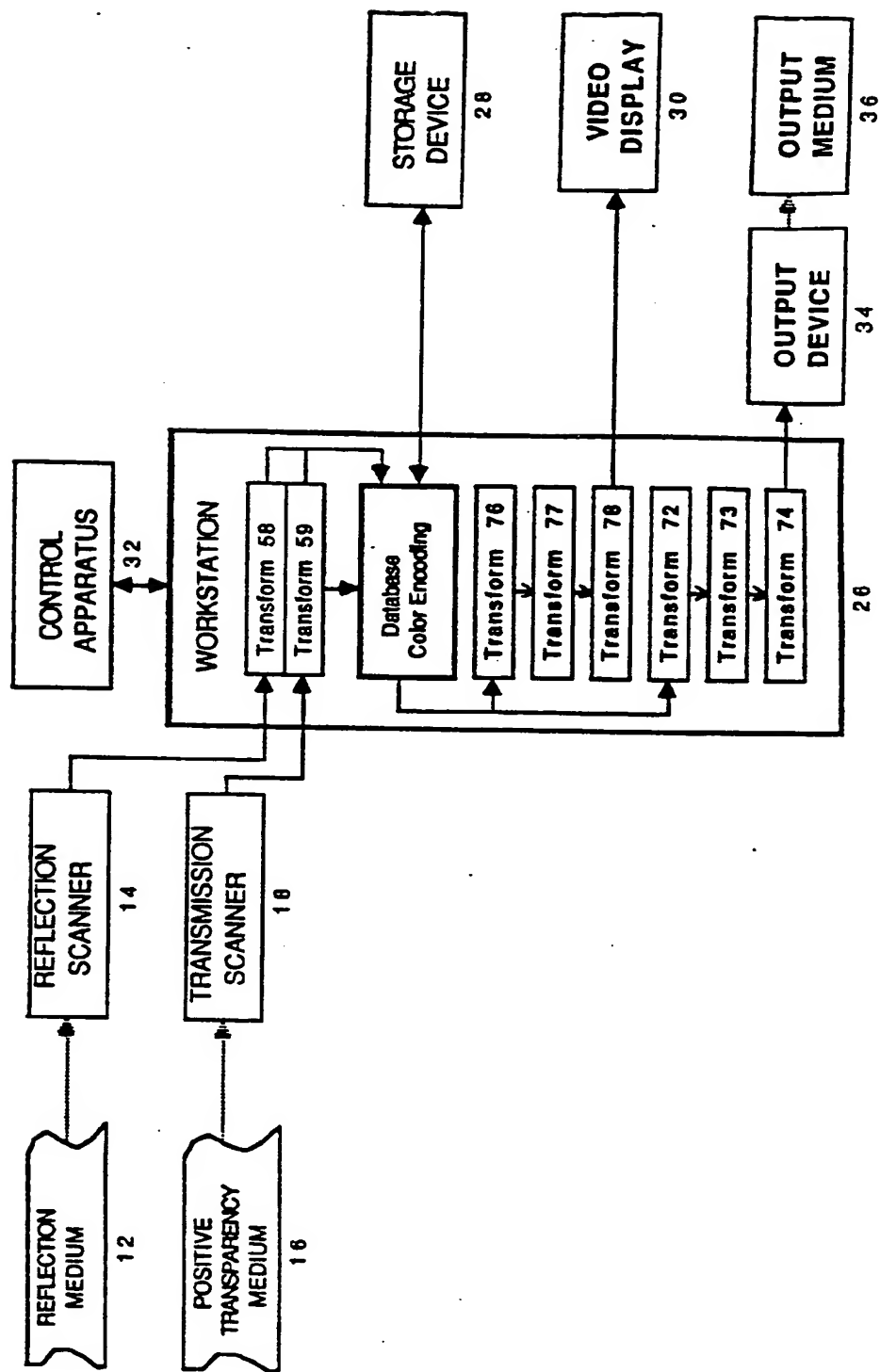


FIGURE 4

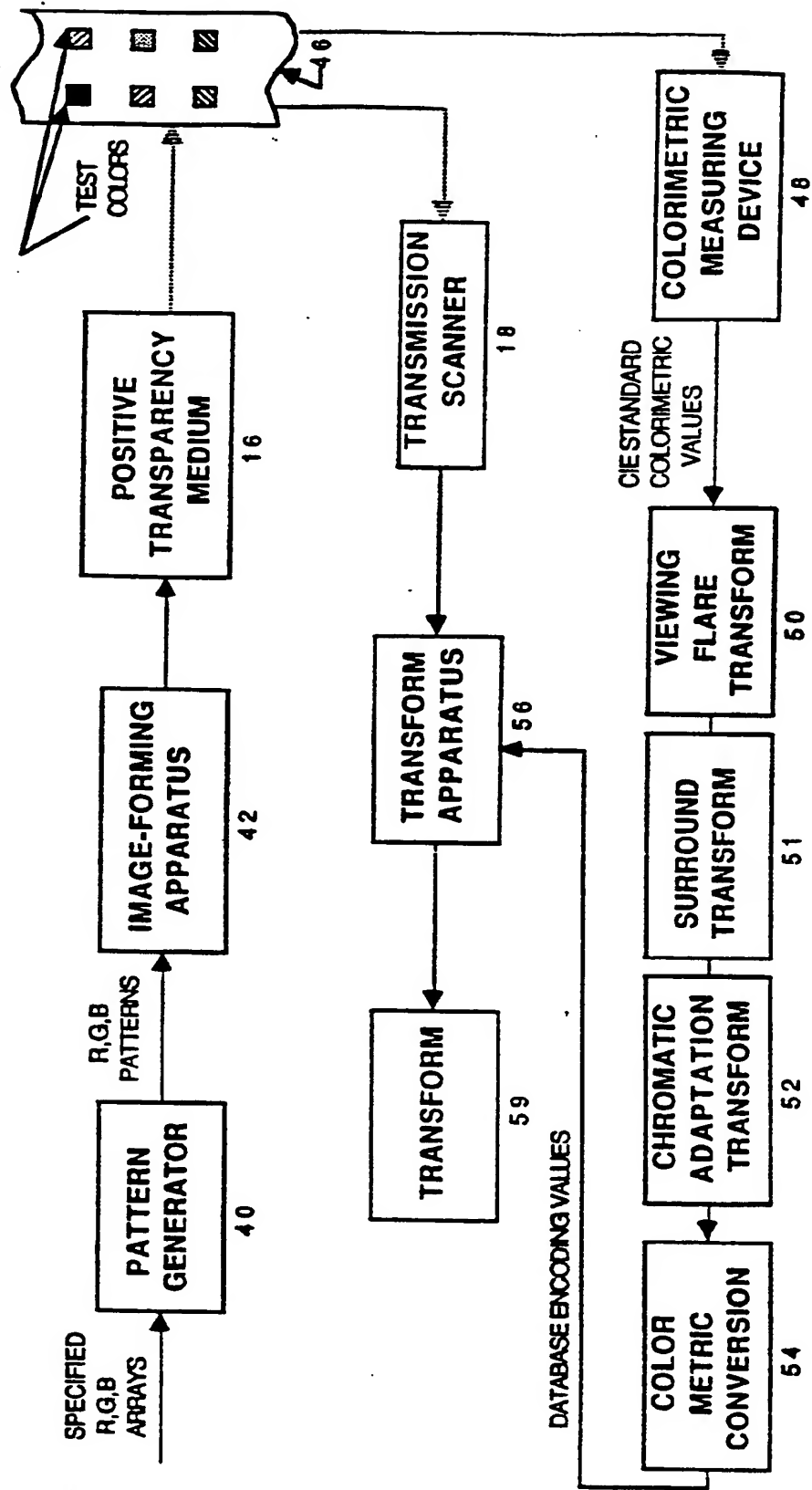


FIGURE 5

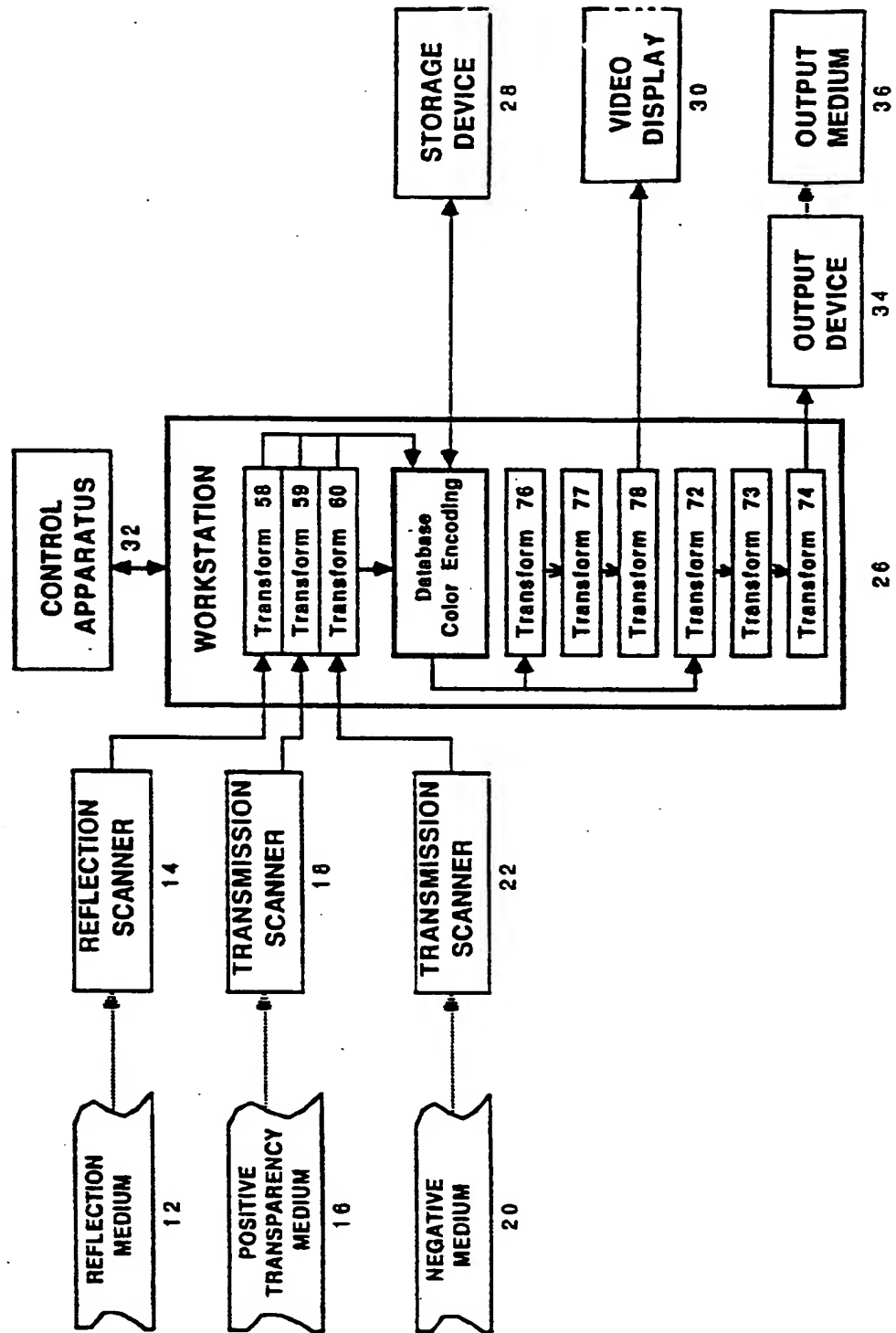


FIGURE 6

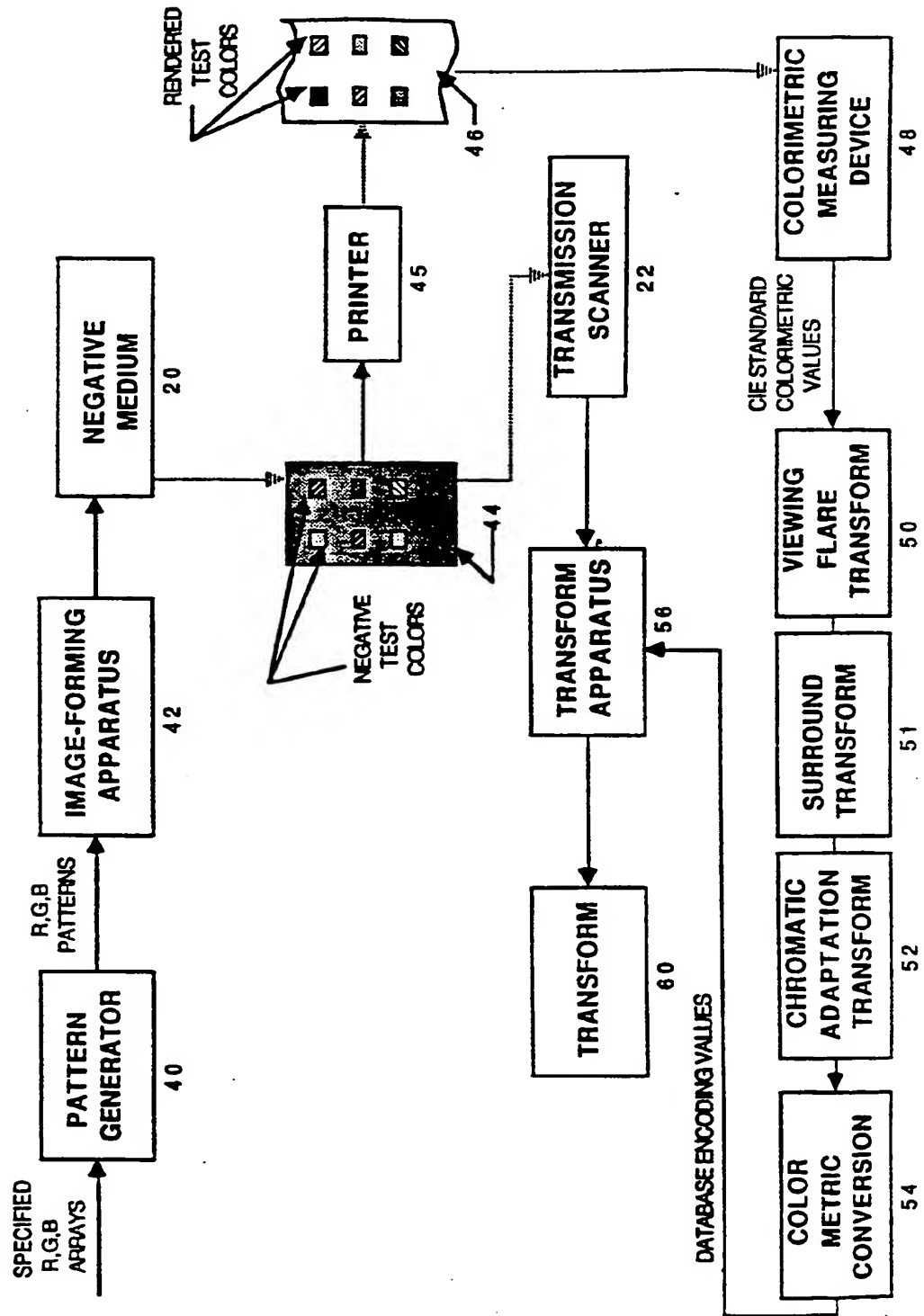


FIGURE 7

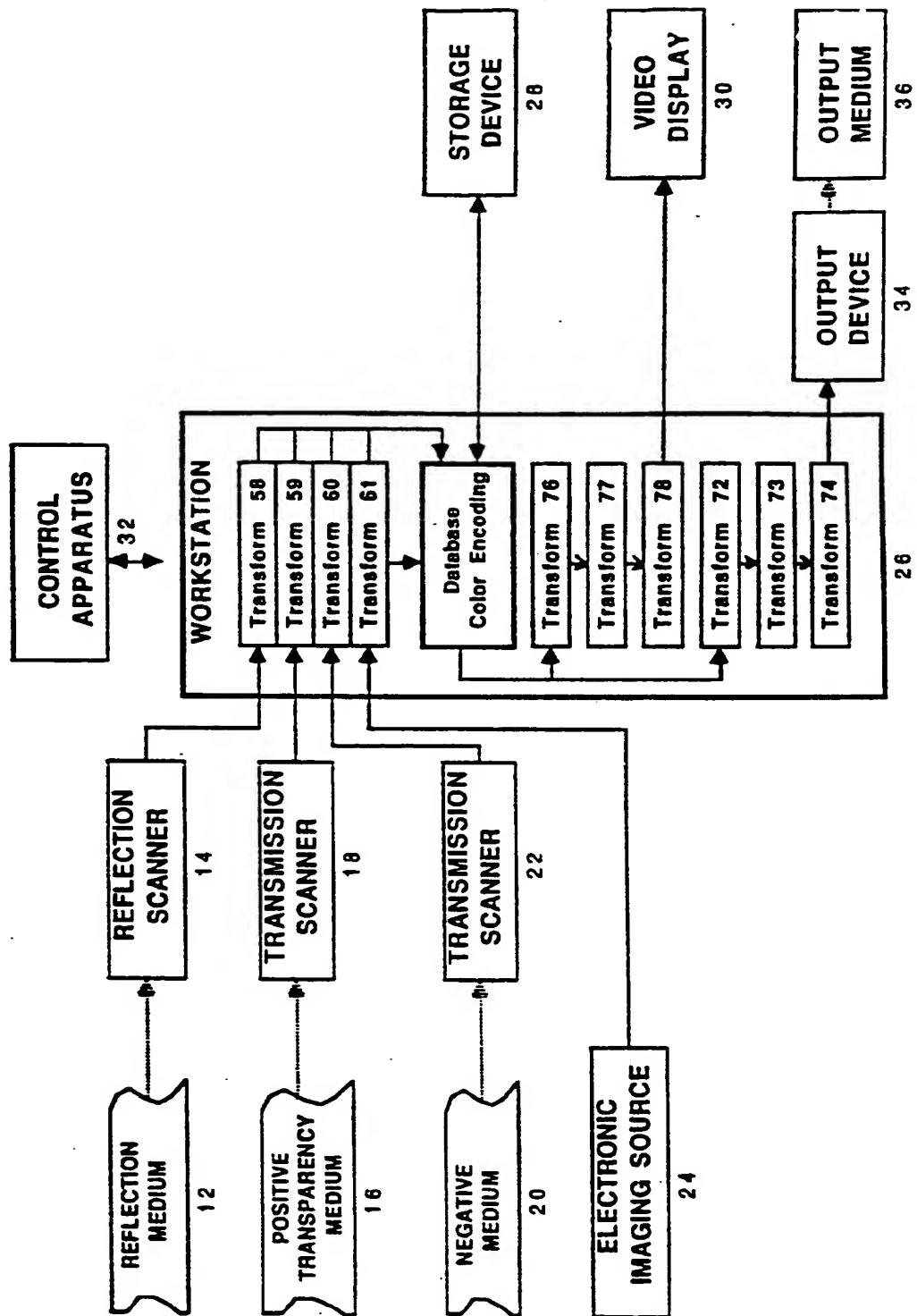


FIGURE 8

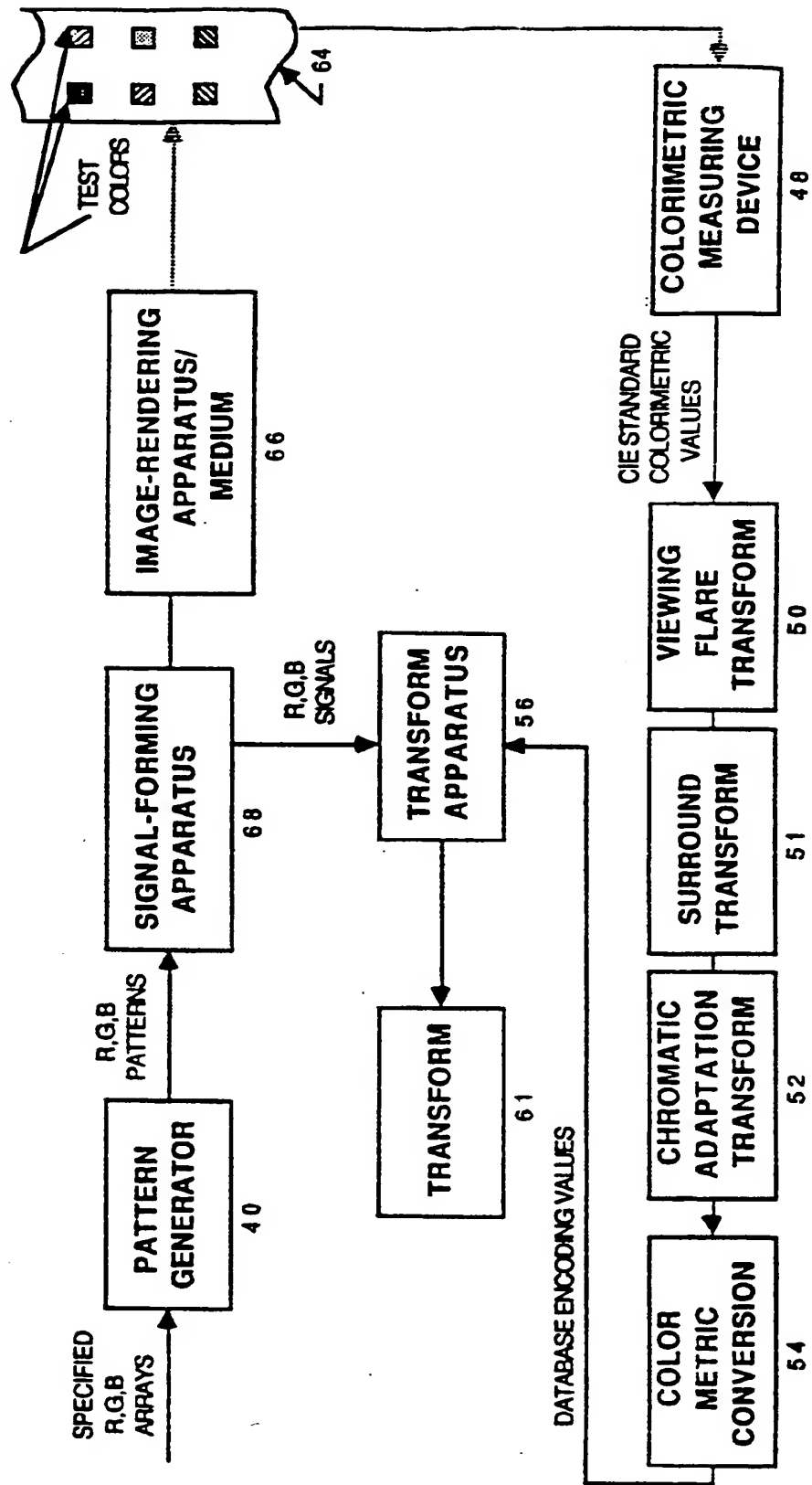


FIGURE 9

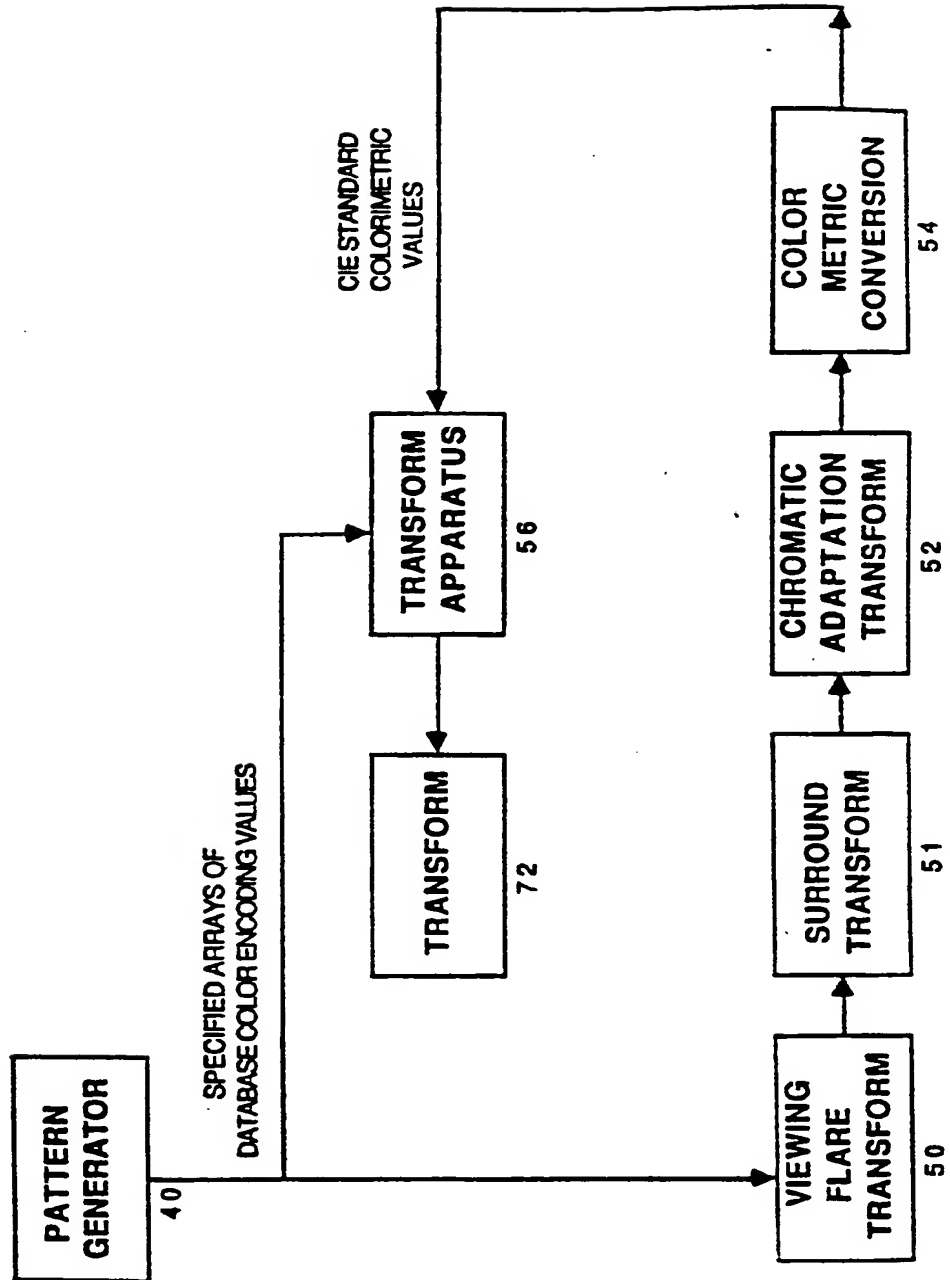


FIGURE 10

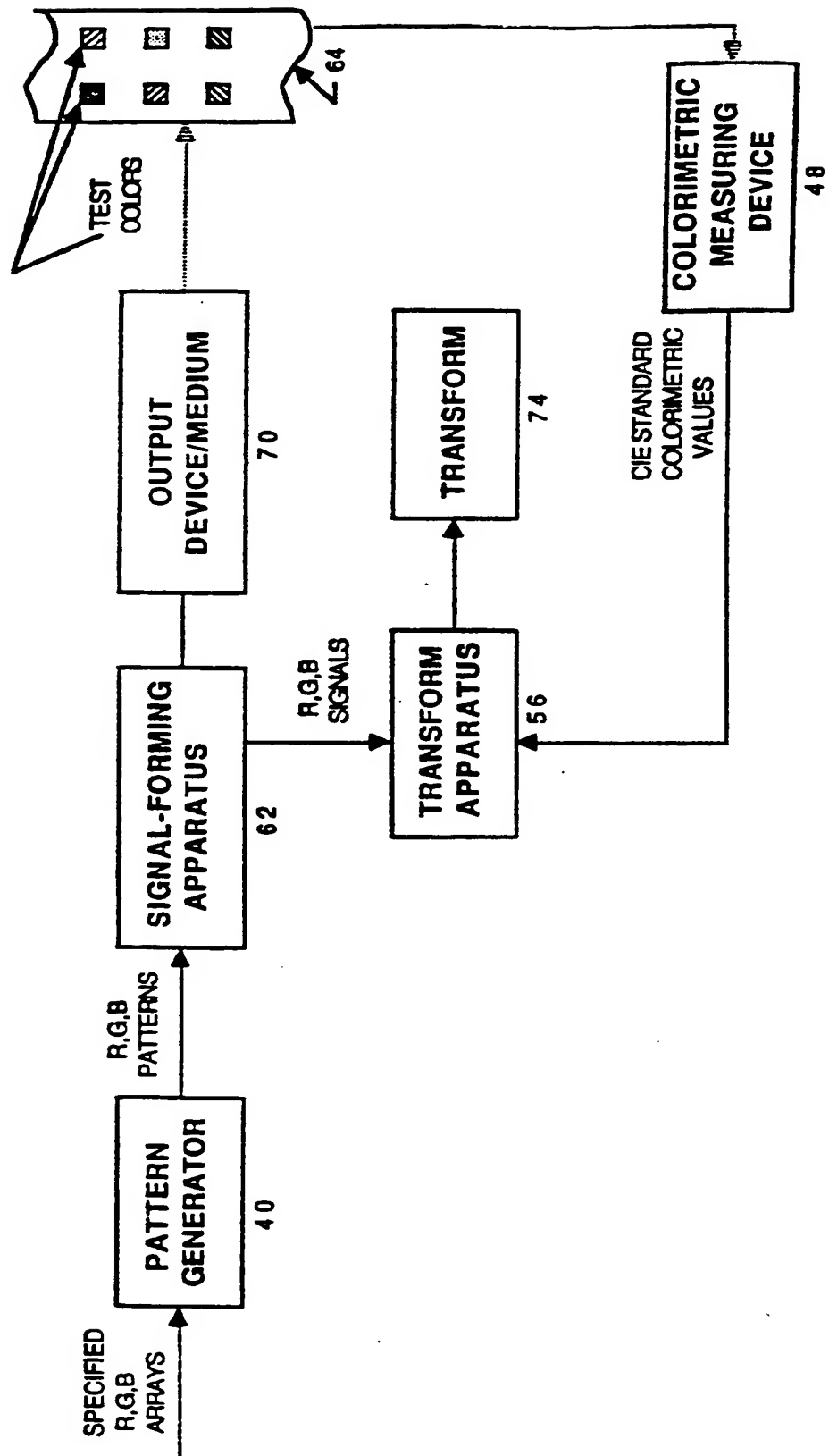


FIGURE 11

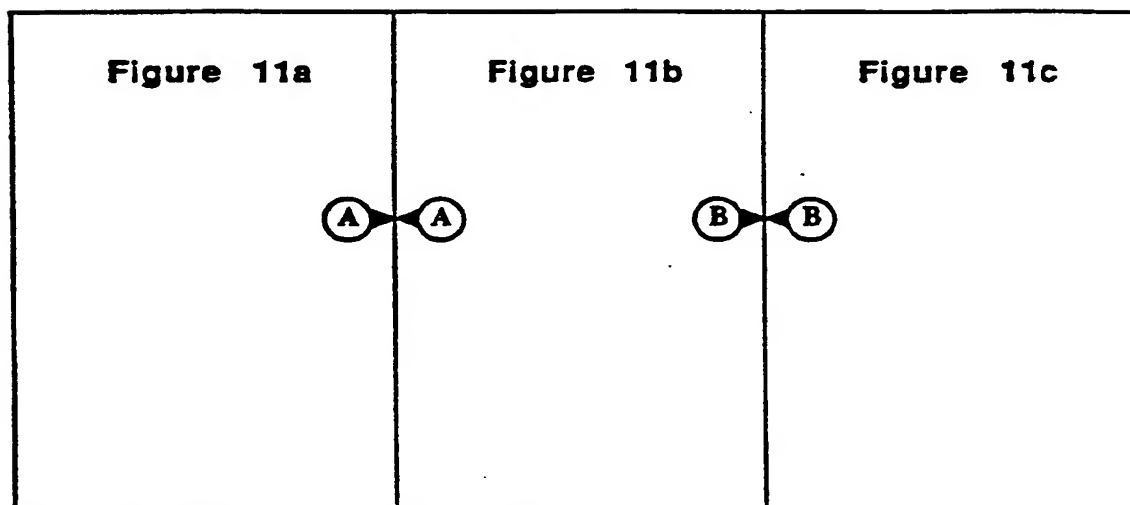
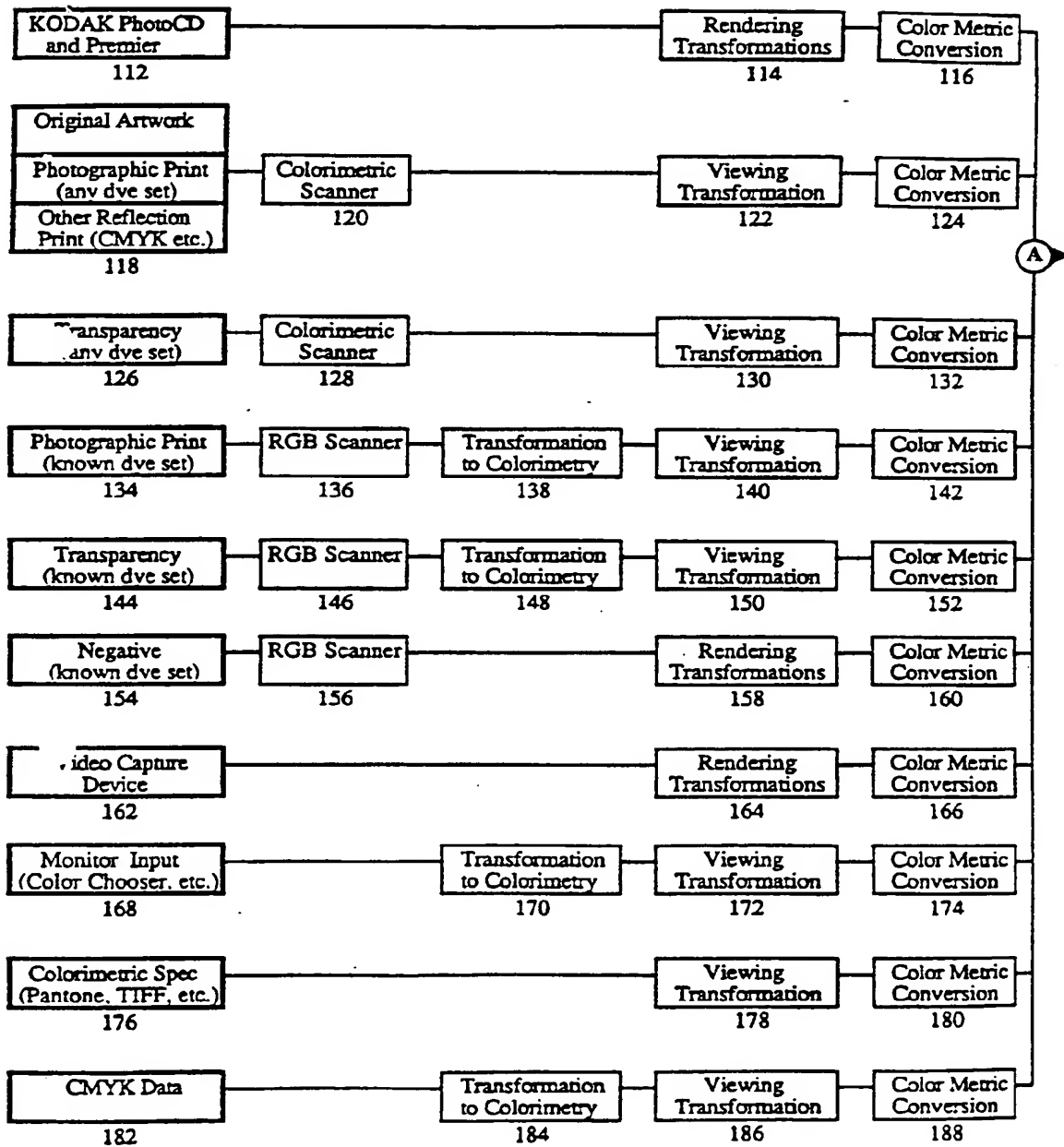


Figure 11a - Inputs



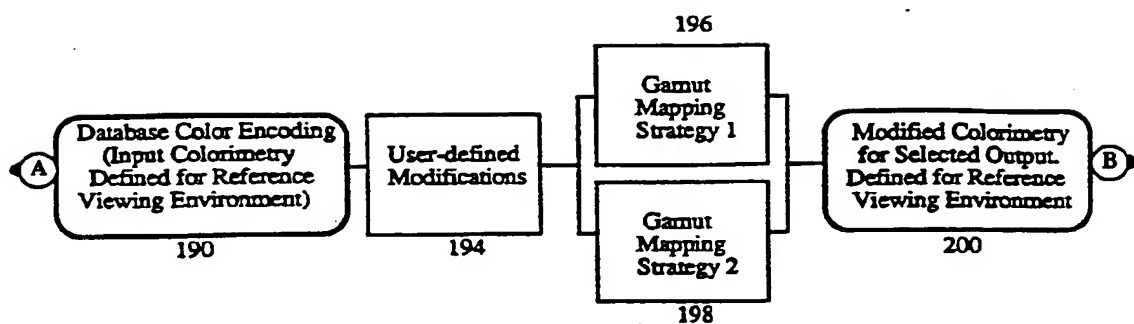
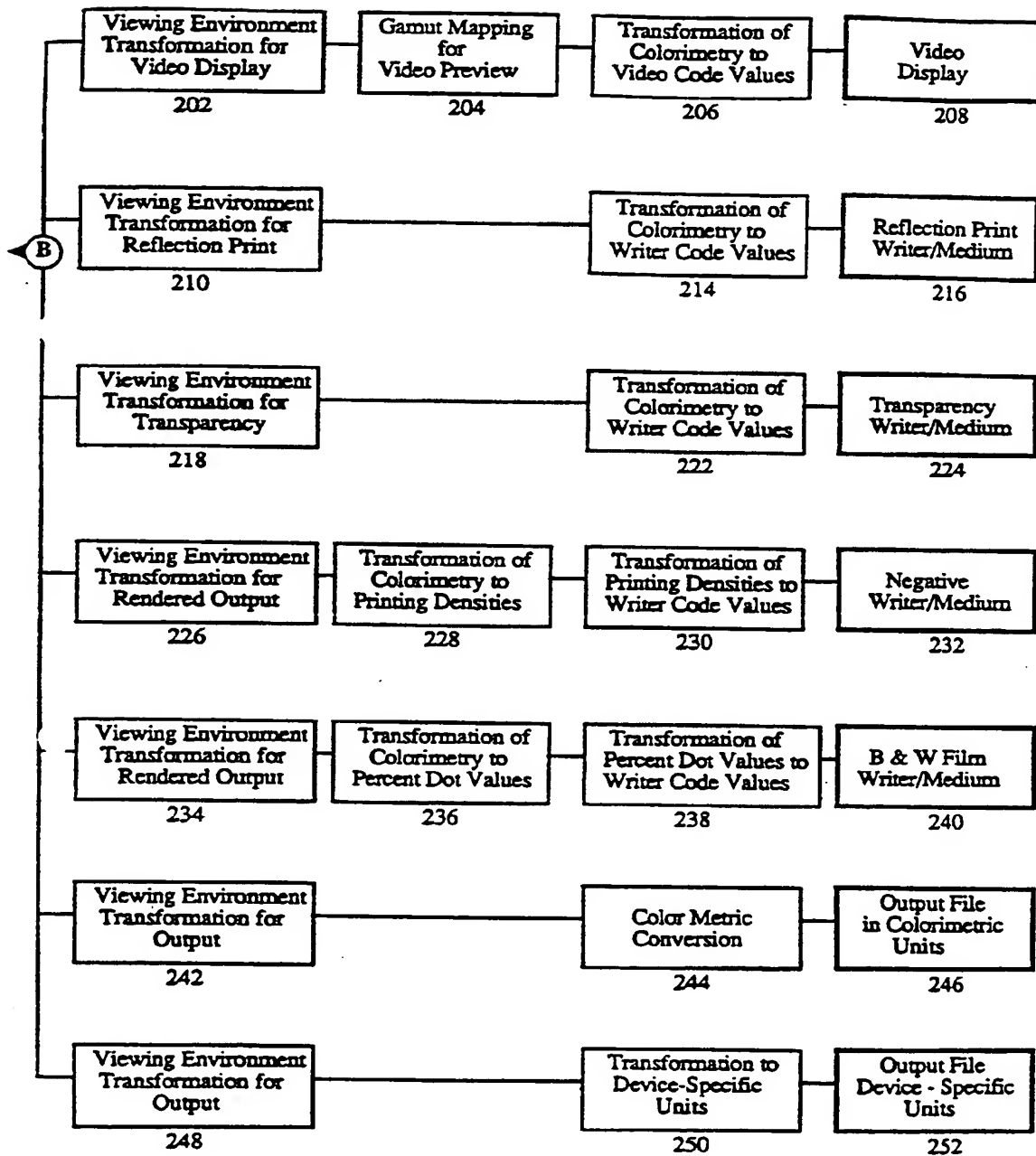


Figure 11c - Outputs



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